



College of Engineering & Computer Science

Senior Design 2

Dynamic Liquid Light Fountain (DLLF)

Developed by:

Group #3:

Peter Bunora

Sarah Weston

Brandy Smith

May 3, 2010

Contents

1	Introduction.....	1
1.1	Executive Summary.....	1
1.2	Motivation	1
1.3	Design Summary	2
1.3.1	Nozzle	2
1.3.2	Cutter Mechanism	2
1.3.3	Power Supply.....	2
1.3.4	LED Drivers.....	3
1.3.5	LEDs	3
1.3.6	Fiber Optics.....	3
1.3.7	System Control.....	3
1.3.8	Pump and Pump Controls	4
1.3.9	Environmental Controls	4
1.3.10	User Controls/Interface	5
1.4	Component Requirements.....	5
1.4.1	Nozzle	5
1.4.2	Cutter	6
1.4.3	Power Supply.....	6
1.4.4	LED Drivers.....	6
1.4.5	LEDs	6
1.4.6	System Control.....	7
1.4.7	Pump.....	7
1.4.8	Pump Controls	7
1.4.9	Ambient Light Sensing Circuitry	8
1.4.10	Passive Infrared Circuitry	8
1.4.11	Infrared Remote Control	8
1.4.12	User Interface	8
1.4.13	Printed Circuit Board.....	9
1.4.14	Weatherproof Enclosure	9
1.4.15	Fiber Optic Transmission Lines.....	9
2	Component Research.....	10
2.1	Research Methods.....	10
2.2	Hardware	10

2.2.1	Power Supply.....	10
2.2.2	System Control.....	18
2.2.3	LEDs	20
2.2.4	LED Drivers.....	22
2.2.5	Color Organ.....	27
2.2.6	IR Remote Control	31
2.2.7	Motion Sensor.....	32
2.2.8	Ambient Light Sensor.....	36
2.2.9	Nozzle Flow Cutter Mechanism.....	37
2.2.10	User interface	41
2.2.11	Pump Controls	44
2.2.12	Printed Circuit Board.....	46
2.2.13	Enclosure.....	48
2.2.14	Fiber Optic Transmission Lines.....	48
2.2.15	Laminar Flow Nozzle	48
2.2.16	Pump	50
2.3	Software	50
3	Design	52
3.1	Design Methods.....	52
3.2	Hardware	52
3.2.1	Power Supply.....	52
3.2.2	Microcontroller Interface.....	53
3.2.3	LED Drivers.....	54
3.2.4	IR Remote Control Circuitry	55
3.2.5	Passive IR Sensor Circuitry.....	56
3.2.6	Ambient Light Sensor Circuitry.....	59
3.2.7	Servo Driver Circuitry	60
3.2.8	Laminar Flow Nozzle and Cutter Mechanism.....	61
3.2.9	Fiber Optic to LED Interface.....	68
3.2.10	User Interface	68
3.2.11	Pump Control Circuitry.....	69
3.2.12	Printed Circuit Board.....	70
3.2.13	Enclosure.....	71
3.2.14	Software.....	71

4	Testing.....	73
4.1	Safety Procedures	73
4.2	PCB Testing.....	73
4.3	Power Supply.....	74
4.3.1	Testing Conditions	75
4.3.2	Measuring Approach.....	76
4.4	LED Driver.....	81
4.5	Pump Controls.....	81
4.6	Nozzle and Cutter Mechanism.....	82
4.7	Motion Detector	82
4.8	Ambient Light Sensor	83
4.9	Servo Driver.....	85
4.10	Microcontroller Software Simulations	86
4.11	Microcontroller and External Circuit Interface.....	86
4.12	Final Testing Phase.....	87
5	User Manual	88
6	Administration and Conclusion	91
6.1	Project Administration.....	91
6.2	Budgetary/Financial Data	92
6.3	Project Timeline	93
7	Conclusion.....	95
8	Table of Figures.....	96
9	Appendix.....	98
9.1	Sources	98
10	Permissions	101
10.1.1	Hitec HS-56HB.....	101
10.1.2	Panasonic	101
10.1.3	Cypress.....	101
10.1.4	RC-5 Protocol	102
10.1.5	Parabolic Velocity Profile	102
10.1.6	National Semiconductor.....	102
10.1.7	Micrel, Inc.	104
10.1.8	Luxdrive	104

1 Introduction

1.1 Executive Summary

The dynamic liquid light fountain (DLLF) is a small home garden accessory that allows the user to enhance the aesthetic value of their yard. This fountain combines optical technology with water jets to display a lighted show. The dynamic liquid light fountain's electronic assembly is housed in a weather proof enclosure containing a printed circuit board with microcontroller; LED drivers; red, blue, and green LEDs; and a DC power supply to power the LED drivers. Mounted outside the electronics enclosure are an ambient light sensor and an IR remote control sensor which allow the user to choose the program from one of the preprogrammed light shows via remote. In the event of a lost remote, the light show can be controlled using the 4 toggle switches located on the electronics enclosure. During the day, in order to save energy and resources, the ambient light sensor determines when the optics will be active, thus only activating the LED drivers when the fiber optics can be seen by the viewers. Also mounted on the electronics housing is a passive IR sensor; this sensor activates the fountain when motion is detected, thus activating a timer that turns off the fountain when motion has not been detected for a prescribed amount of time.

The LED's optical output is driven to the laminar flow nozzle via fiber optic cabling. The laminar flow nozzle and the flow cutting mechanism are driven by a servo motor which is controlled by the electronics assembly. The water level in the fountain is monitored by the pump control circuitry. This circuitry consists of a low level switch which disengages the fluid pump when low water levels are detected and then feeds information back to the microcontroller to facilitate the shut-down of the LED's and LED drivers.

This project was diverse enough to allow for the development of individualized tasking for team members. One member was tasked with microcontroller program development, while another developed the LED driver and power supply assembly. The third team member tackled the electromechanical aspects (pump and laminar flow) as well as the peripheral interface.

1.2 Motivation

Our group was motivated by a desire to enhance the appearance of the everyday home garden. Today people strive to have the outside of their homes reflect their personal tastes, and express their individuality. By bringing this project to fruition, we have increased the aesthetic appeal of the average home garden.

This project also allows us to incorporate various aspects of electrical engineering while still preserving an individual and unique senior design project. Furthermore, this project encompasses the specialties of analog power design, digital design, embedded systems, and fiber optic transmission. Because of our

use of pumps, motors and laminar flow nozzles, we are also delving into the electromechanical field. The broad spectrum of topics covered by this project not only allows us to produce an aesthetic pleasing end result, but it allows further development of our core skill set. Lastly, it allows us to broaden our engineering knowledge in areas we may not have previously encountered.

1.3 Design Summary

The Dynamic Liquid Light Fountain contains mechanical as well as electrical components. The design summary explains the expected function of each of these individual pieces of the Dynamic Liquid Light Fountain. These descriptions were integral in development of the component requirements.

1.3.1 Nozzle

The main function of the each nozzle is to generate a laminar stream of water. Laminar flow is achieved when the fluid flows in parallel layers with little or no disturbance between the layers. Other characteristics of laminar flow are that velocity and pressure are independent of time, the momentum of diffusion is high and the momentum of convection is low. Essentially laminar flow is the opposite of turbulent flow. When laminar flow is achieved, the water has a smooth, almost glass like appearance. Furthermore, this laminar flow of water allows for the transmission of light, similar to fiber optic cable. Light from the LEDs is transmitted through the water and into the collection pool. The goal is to create a laminar stream that has a diameter of at least $\frac{1}{4}$ " but no more than $\frac{1}{2}$ ".

1.3.2 Cutter Mechanism

The cutter mechanism is mounted onto each nozzle and is controlled via the microprocessor. The function of the cutter is to temporarily block or redirect the laminar stream of water. By blocking or redirecting the stream of water, it provides the illusion that the water is "jumping" from one location to the other. In order to provide the most intact stream of water when the stream is blocked or unblocked the cutter must move rapid into and out of the stream. A slow moving cutter can cause major disruptions in either the leading edge of the stream, when it is unblocked, or in the trailing edge of the stream when it is blocked. The goal of the cutter is to completely block the stream of water will providing minimal disturbance to the stream's leading or trailing edges during its operation.

1.3.3 Power Supply

The backbone for any electronics project is the power supply. Without a means of supplying power, nothing can be powered up and utilized. Our project requires both alternating current (AC) and direct current (DC) voltage. The pump requires 115 volts AC at 60 Hertz, and the LED driver, microcontroller, and other various circuits require 5 volt DC power. Our proposed power supply consists of an iron core transformer, a bridge rectifier, a filter capacitor and a voltage regulator. The

power supply provides a constant voltage and delivers a current of 1.5 amps. It is mounted inside the main enclosure.

1.3.4 LED Drivers

We are using high powered LEDs to create the various color combinations desired for the DLLF. One of the simplest and most inexpensive ways to provide power to a LED circuit, and the way that is recommended by most, is a constant current source. Typically, it consists of a small integrated circuit and several other outside components. The result is a constant current supplied to the LEDs no matter what type of input voltage exists or what type of forward voltage drop the LED has, which is especially important to consider when using high-power LEDs such as the ones we are utilizing for the DLLF.

1.3.5 LEDs

The Dynamic Liquid Light Fountain includes design for LED (or Light Emitting Diode) lighting when the fountain is operating in the dark or when operating after turned on by the motion sensor. LEDs have many benefits over other traditional lighting sources such as their compact size, lower energy consumption, faster switching ability, and lower power consumption. We are using three different colors with which we can use pulse width modulation to combine and form any color of the rainbow on the stream of water provided by the pump and cutting mechanism. Our main focus is on LED performance including maximum current through the LED, forward voltage, power consumed, and cost.

1.3.6 Fiber Optics

In order to transfer the light from the LED's to the laminar flow nozzle, we are using a LED/Fiber coupler. The coupler sits over the LED and creates an interface between the LED and Fiber cabling. Through this coupler, the light from the LED travels down the fiber cabling to the laminar flow cutter. At that point, the light is transferred to the water. The fiber optic cabling is housed within the cutter mechanism. The intensity of the light is determined by the distance of the fiber from the nozzle opening.

1.3.7 System Control

This project uses a central control unit which must be robust enough to complete the following actions. The unit contains four user-selectable programs which, when selected, run in a loop until the user selects a new program for display. A fifth program is also available; this program causes the LED's to "dance" to the music given an audio input to the RC jack. These programs may be chosen by the user via the IR remote control or the user interface switches. The control unit also monitors the signals from the remaining peripherals to determine if the selected program should be executed. If the light sensing circuitry determines that the ambient light situation is such that the LEDs cannot be viewed, the control unit continues to execute the program without driving the LED's. The

passive infrared circuitry monitors the motion surrounding the fountain; if it is determined that there is no one in the surround area the control unit turns off the fountain in an effort to keep electricity consumption to a minimum. In addition to driving the LED's, the control unit programs also control the cutter motors through pulse width modulation to vary the laminar flow. The cutters open and close in four different patterns according to the four programs, this gives the appearance of dancing liquid light. If the water level becomes too low, the control unit turns off the LED drivers and turns off the pump to prevent dry running the pump.

1.3.8 Pump and Pump Controls

This circuit is responsible for protecting the pump when low water levels exist. When low levels have been reached, the sensor sends a signal to a relay which, as a result, shuts down the pump; a signal is also sent to the microcontroller. The microcontroller then begins powering down the Dynamic Liquid Light Fountain. When a safe water level has been reestablished, the relay closes and the circuit resets. At this point, the Dynamic Liquid Light Fountain resumes normal operations. The pump provides enough flow and sufficient lift to the two flow nozzles to generate the desired laminar stream of the specified diameter, arc height and length. The discharge from the pump has minimal amount of surging which allows for a more consistent arc height and length out of the nozzles. Excessive surging makes the stream appear unstable.

1.3.9 Environmental Controls

1.3.9.1 Ambient Light Sensor

In order to conserve energy and to extend the life of the LEDs, a day/night sensor provides an input to the microprocessor. During full daylight, the visibility of the light from the LEDs is extremely low; therefore there is no need to have the LEDs in service. However, the cutting mechanism is still operational to allow enjoyment of the fountain during the daytime hours. Once the daylight is below a predetermined level, the LEDs are placed back in service to maximize the user's enjoyment of the fountain.

1.3.9.2 Passive Infrared Motion Sensor

In order to conserve energy as well as to extend the lifetimes of the pump and LEDs, a passive infrared motion sensor provides an input to the microprocessor. The motion sensor detects movement within 10 feet of the fountain and initiates the fountain sequence. If after a predetermined time no motion is sensed then the microprocessor places the LEDs and the water pump in standby mode. Once motion is sensed, the microprocessor brings the fountain out of its standby condition and restores the fountain to its proper operating condition based on the environmental conditions.

1.3.10 User Controls/Interface

1.3.10.1 IR Remote Control

The infrared remote control utilizes an ordinary infrared remote control to interface with the fountain. The remote control inputs are used by the microprocessor to initiate preprogrammed light and cutter sequences. Each preprogrammed sequence corresponds to a number on the remote control. It also allows the user some basic controls over the primary LED colors, i.e. just red or just blue, just green, or any combination of the three. Moreover, it allows the user to turn on and off the individual cutters as desired.

1.3.10.2 User Interface

The user interface provides some basic controls for manual operation of the fountain. Next, the user interface provides a means to turn the system and or the pump on or off. It also allows the user to turn any or all of the LED primary colors on to full intensity. Finally, the interface allows for control of the individual cutting mechanisms, and it provides a port to allow the user to modify the microprocessor coding as he or she sees fit.

1.4 Component Requirements

The sections below outlines the requirements set forth by our group to build the Dynamic Liquid Light Fountain. These requirements lay out the goals we are working towards achieving for the individual aspects of the DLLF. By meeting the following individual requirements we have successfully created a fountain that combines optical technology with water jets to display a lighted show.

1.4.1 Nozzle

Due to the group being the sole sponsor of the project, certain restrictions were needed to limit the cost of the project. In order to hold down costs, the size of the pump was scaled down from our original concept. In scaling down the size of the pump the flow rate and lift of the pump was ultimately reduced. This reduction in flow rate and lift limited the capabilities of the laminar nozzle. With these limits in mind, we needed to reduce the diameter and arc length of the water stream to within the pumps physical capabilities and still maintain a certain amount of aesthetic value. As a result, the nozzle generates a laminar stream of water with the following characteristics:

- A diameter of at least $\frac{1}{4}$ " and no more than $\frac{1}{2}$ ".
- The stream maintains its integrity throughout its entire length.
- The stream travels at least four feet from the exit point of the nozzle.
- An arc height of at least two feet above the exit point of the nozzle.

1.4.2 Cutter

For the cutter to allow the stream of water to remain as laminar as possible, it moves into and out of the stream as fast as possible. A fast acting cutter gives the stream a more defined appearance at the leading or trailing end depending on if the stream is being cut or uncut. In order to achieve the desired results, the cutter mechanism meets the following requirements:

- The cutter completely blocks the laminar stream of water from the nozzle.
- The cutter causes minimal disturbances in the stream during its operation.
- The actuating mechanism operates utilizing a 5 VDC power source.
- The cutter can complete its full travel in less than 0.15 seconds in either direction.

1.4.3 Power Supply

We have included a power supply that provides 115 volts AC and 5 volts DC power. We will use a standard wall outlet and plug to get the AC voltage. To reach the desired DC voltage, we designed a circuit that converts 115 volts AC to 5 volts DC using typical circuitry including a transformer, bridge rectifier, filtering capacitance, and voltage regulation. A maximum current of 3.0 amps can be drawn from this power supply. Should we require more current after building and testing all components, we must modify the power supply accordingly by either adjusting the voltage regulator or adding additional circuitry.

1.4.4 LED Drivers

The requirements of the LED driver include, but are not limited to the following:

- Provides continuous current to each LED
- Receives PWM signal from microcontroller
- Operates off 5 volts.

1.4.5 LEDs

We have incorporated 2 sets of three color LEDs in our project including red, blue, and green. These lights are high powered and combine to produce an array of colors that light up the water as it flows from the fountain. The majority of indicator LEDs specify their characteristics at a current of 20mA with a typical forward voltage of 2-4 volts DC. However, illumination LEDs, such as the ones we are using in our project, usually have larger junctions and can draw more current, using more power and providing a brighter output. A standard drive current for a high power LED is 350mA and dissipates around 1watt of power. We will use 3 watt LEDs which require more power but also provide more brightness.

1.4.6 System Control

The system control runs off of 5 volts DC has a minimum of 32I/O pins, including at least 2 pulse width modulated I/O pins. The microchip is also capable of using an external clock reference, which is needed for the Infrared remote control. The chip also has 10KB of program memory to store the 4 user programs.

The system control is capable of handling the following inputs:

- 6 for the automated program selection
- 1 manual cutter control
- 1 water level
- 1 IR remote control
- 1 day/night sensor
- 1 motion sensor
- 1 initiating manual control of LEDs
- 6 LED manual on/off
- 1 external oscillator (for IR remote control)
- 1 color organ

The microcontroller is also able to drive the 6 LED driver outputs as well as 2 pulse width modulated outputs to drive the cutter arm. There is also 1 output for the pump controls.

1.4.7 Pump

The pump can provide enough flow and sufficient lift to the two flow nozzles to generate the desired laminar stream of the specified diameter, arc height and length. To ensure that these requirements for the system were met, the pump satisfied the following requirements:

- The pump has a discharge flow rate of at least 500 gph.
- A minimum of 25 feet of lift.
- Utilizes 120 VAC single phase power source.

1.4.8 Pump Controls

The pump control circuitry is responsible for protecting the pump from running dry, a condition that would significantly reduce the life of the pump. The circuit contains a relay that operates in the normally closed position. The normally closed relay allows the pump to remain active while water levels are considered at a safe level. When the water level drops, a float switch deactivates the normally closed circuit and turns off the pump. This circuit is also responsible for ensuring that the microcontroller does not run when there is no water output. The circuit runs off the 5 volt DC power supply. Lastly, it turns off the pump when water levels fall below 6 inches, preventing the pump from running dry.

1.4.9 Ambient Light Sensing Circuitry

Since during daylight hours the light from the LEDs is not visible, we will turn the LEDs off during periods when they are not easily visible. This allows our project to be more energy efficient. The circuitry is adjustable so that the user can set the level of daylight necessary to power down the LEDs. It also conforms to our design of a single voltage power supply rather than a dual voltage power supply. In order to operate the fountain in this manner, the following properties of an ambient light sensing circuit were required:

- The sensor is adjustable to allow the user to fine tune the point at which the LEDs are enabled or disabled by the sensing circuit.
- The sensor circuitry can be operated utilizing a 5 VDC power source.

1.4.10 Passive Infrared Circuitry

Continuing with our desire to be more energy efficient, the fountain is not operational when there is no one around to appreciate it. Therefore, the system incorporates a motion sensing circuit to provide an input to the microcontroller. When no motion has been sensed in a predetermined amount of time, the microcontroller shuts down the pump and LED drivers (if they are in operation). In order to accomplish this, the following sensor requirements were met:

- Can detect motion within 10 ft. of the fountain
- Has a vertical detection field of $\pm 22.5^\circ$
- Has a horizontal detection field of $\pm 45^\circ$
- Operates utilizing a 5 VDC power source.

1.4.11 Infrared Remote Control

To aid the user in the operation of the fountain, the use of an infrared remote control is incorporated into the design. This allows the user to control which sequence of lights and cutter actuation occur and also enables the user to power the system up or down. To accomplish this, the infrared remote control provides the control for the following:

- 6 preprogrammed LED sequences
- Each of the primary LED colors
- Individual cutter mechanisms
- Pump power.
- System power.

1.4.12 User Interface

The user interface allows the user to manually operate the fountain, and it is also used for troubleshooting purposes. The interface has a means for the user to access the programming of the microcontroller to make alterations to the code. Since we wanted to make the interface meaningful, it reproduces most of the

functions of the infrared remote control. With this in mind, the interface provides controls for the following functions:

- Rocker switch to control system power.
- Rocker switch to control pump power.
- DIP switches allowing individual control of each LED color.
- DIP switches for selecting the preprogrammed fountain sequences.
- Momentary pushbuttons to actuate each of the nozzle cutters.

1.4.13 Printed Circuit Board

The PCB is a 2-layer, single-sided FR-4 board approximately 0.062" thick. This board is 60 square inches, which adheres to the student pricing restrictions imposed by 4PCB, the fabrication company with which we chose to fabricate our PCB. The PCB contains the following circuitry:

- LED drivers
- Microcontroller circuitry
- Peripheral interface
- Pump controls
- DSP circuitry
- 5V Power Supply
- Color Organ

1.4.14 Weatherproof Enclosure

The weather proof container houses all circuitry and also has the peripheral sensors mounted outside on the top. Pass through openings are located on the sides of the box to allow power into the enclosure and to allow the fiber optics and pump control lines out. The enclosure is non-rusting and has a removable lid for testing and troubleshooting purposes. The max dimensions for this enclosure do not exceed 20"x21"x7".

1.4.15 Fiber Optic Transmission Lines

The fiber optic transmission line are responsible for ensuring the optical output from the LED drivers is efficiently transferred from the LED to the laminar flow nozzle. The lines are of sufficient length to comfortably extend to the pump and basin portion of the project. There is one fiber optic cable per LED, for a total of 2 transmission lines (since we are using 2 RGB LEDs). The LED drivers are grouped together in 2 groups, each group containing a red, blue and a green LED color. The transmissions lines run together from one LED to one laminar flow nozzle. The fiber optic transmission lines are housed within the laminar flow nozzle allowing the transfer of light to the water. The transmissions lines are adjustable within the nozzle allowing the user to increase or decrease the distance between the fiber optic termination and the nozzle opening. This allows the user the ability to adjust the nozzle for optimal transfer of light to the water.

2 Component Research

2.1 Research Methods

In order to most effectively research the components and design ideas for this project, we began by brainstorming ideas that would incorporate well into our project. Because the project was our own creation there were no restrictions to the items that we may include in the Dynamic Liquid Light Fountain. The first decision we made before research began was which voltages we would like to use. For diversity of component availability we chose to use a 5 volt DC supply. By choosing this value, we had a large amount of parts to choose from. After determining the voltages, we divided the research responsibilities among the group members so that we were not researching the same parts. We then spent the next few weeks researching any options that we thought would benefit the overall outcome of the liquid light fountain. The following section contains the research we conducted as well as reasoning why we did or did not incorporate these items into our Dynamic Liquid Light Fountain.

2.2 Hardware

2.2.1 Power Supply

The backbone for any electronics project is the power supply. Without a means of supplying power, nothing can be powered up and utilized. Because of the diverse technology that exists today, many power supply circuits have been designed, built, tested, and used. After doing research on the various circuits available to us and after applying the knowledge we have gained throughout our coursework, we know that there are a few basic components of a power supply.

The DLLF requires both alternating current (AC) and direct current (DC) voltage and so we considered the general structure of a linear power supply shown below in Figure 1 in our design.

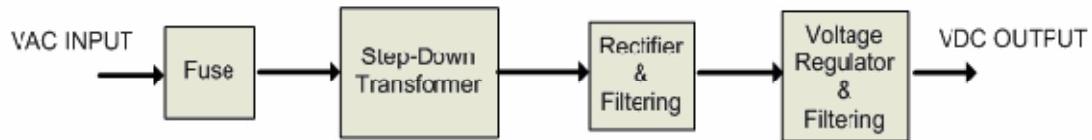


Figure 1: General structure of a linear AC to DC power supply

More specifically, our power supply consists of an iron core transformer, a bridge rectifier, a filter capacitor and a voltage regulator. The component in our project that will consume the largest amount of power is the water pump, and it requires 115 volts AC. Since the majority of electrical outlets in the United States provide 120 volts alternating at 60 cycles per second (or 60 Hertz), we are utilizing a wall outlet to power up the pump. The majority of pumps used are already fused so,

after we verified that a fuse exists, we decided we do not need to add an additional fuse for protection. We are definitely adding a fused switch between the AC power supply and the transformer, however, in order to protect the circuit from any power surges.

2.2.1.1 Step-Down Transformer

Since the remaining items in our project, the microcontroller and the LED driver circuitry, require 5 volts DC, we needed a step-down transformer immediately following the AC input and the fuse. Simply put, a transformer is a device that changes electrical energy in AC circuits. In order to change this energy, a transformer uses magnetic coupling between sets of coiled wires, transferring energy from one circuit to another. The basic concept of a transformer is shown below in Figure 2.

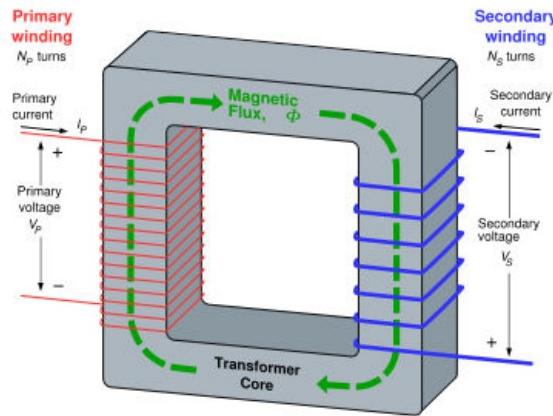


Figure 2: Typical transformer (Image used with the permission of Wikipedia GNU Free Documentation.)

In our case, we are changing our primary voltage from 120 volts AC to a secondary voltage of 6.3 volts AC. Thus, we needed an iron core transformer with a turns ratio resulting in an output of 6.3volts AC. This ratio is determined using the formula $V_s/V_p = N_s/N_p$, where V_s is the secondary voltage, V_p is the primary voltage, N_s is the number of turns in the secondary coil, and N_p is the number of turns in the primary coil. Even though this equation is specifically for an ideal transformer where there are no energy losses, it is also used to approximate almost any transformer since they are considered efficient devices. Since our primary voltage, V_p is 120 volts and our secondary voltage, V_s , is 6.3 volts, our secondary to primary turns ratio is 0.0525. Rearranging the equation gives us $0.0525N_p = N_s$. So, for every 20 turns of primary, there should be 1.05 turns of secondary. We could have used a transformer with one of the following winding configurations: non-tapped, center-tapped, or multi-tapped. These "taps" refer to the primary windings, the secondary windings, or both in some cases. This enables the user to utilize only some of the windings in order to regulate the

output voltage. For example, if we had decided to use a transformer with a center-tapped secondary, the transformer is operating based on the full ratio of the primary to half that of the secondary, meaning that only half of the secondary voltage is found across each coil. The non-tapped transformer is the one most commonly used since it fully utilizes both the primary and secondary coils at all times.

When designing a power supply, heat and the winding resistance of the transformer are of concern. Resistive losses are incurred due to the windings of the transformer with some of these losses resulting in the production of heat. The cross sectional area of the transformer coil and the type of material used for the wire determine the total resistance of the coil. Since a larger current is typically required in the secondary coil than in the primary coil of a step-down transformer, the secondary coil has a larger diameter than the primary. These are all factors we considered when choosing a transformer to step-down the primary voltage for our project. One transformer that we researched that would have worked for the DLLF if we would have needed less than 3 amps of current is manufactured by Pulse and it is a 115V to 6V 2.67A, 12.0va, power transformer. This transformer has a maximum power rating of 12.0va, an input voltage and frequency of 115V 50/60 Hz. and a voltage regulation of 19% at full load to no load; it can provide the 6.3 volts we need. This transformer was available from Digi-Key for approximately \$6.78.

2.2.1.2 Rectification

Now that our circuit is supplying an AC voltage of 6.3 volts, we are taking that voltage and converting it to DC voltage, which is also referred to as “rectification.” We are rectifying our circuit so that either polarity of input voltage (positive or negative) will be output as one polarity. We could have rectified our circuit using either a non-center-tapped transformer and 4 diodes (also known as a “bridge rectifier”) or a center-tapped transformer and 2 diodes. The advantage of a non-center tapped transformer was that we would have been fully utilizing the secondary coil; the disadvantage was that there were 4 diodes required (rather than 2) which meant there were 2 diode drops in voltage. An example of a non-center-tapped transformer rectifying circuit is shown in Figure 3.

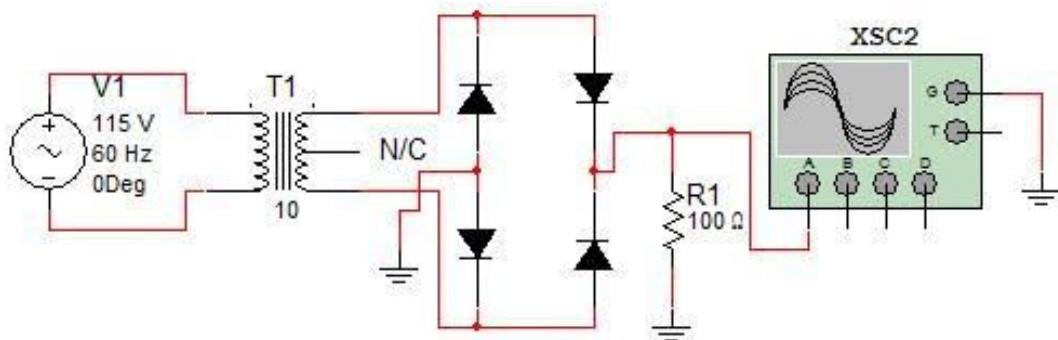


Figure 3: Non-center-tapped rectifying circuit

For the center-tapped transformer, the advantage is that we are only using 2 diodes which means there is only 1 diode drop in voltage; the disadvantage of this transformer is that twice the number of secondary windings are required for the same amount of voltage which then increases its size and, ultimately, it increases the cost of the transformer. An example of a center-tapped transformer rectifying circuit is shown in Figure 4. We are using a non-center-tapped transformer with a bridge rectifier for our power supply.

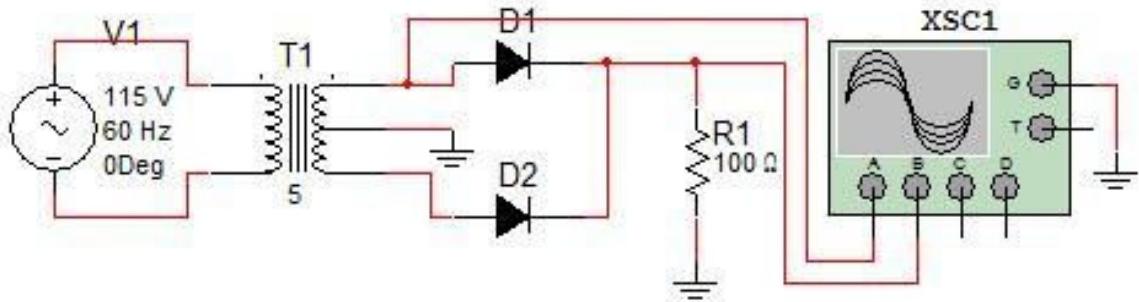


Figure 4: Center-tapped rectifying circuit

2.2.1.3 Diodes

In order to ensure good regulation, we considered substituting the conventional bridge rectifier with four power schottky diodes (Johnson, 2009). Compared to a typical P-N junction diode with a forward-voltage drop of 0.7-1.7 volts, the schottky diode has a very low forward-voltage drop of 0.15 to 0.45 volts (Wikipedia). During implementation of the bridge rectifier, if we used standard silicon diodes, we would have an approximate voltage drop of 2 volts, whereas, using the schottky diodes, our voltage drop is only about 1 volt. When designing any type of electrical circuit, efficiency should always be considered. So, if there is less voltage drop, there is less power lost, and therefore, the circuit is more efficient. Another advantage is that schottky diodes can achieve greater switching speeds than p-n junction diodes because of their low depletion width, again making them appropriate to rectify high frequency signals.

2.2.1.4 Filtering Capacitance

At this point in our power supply circuit, we have taken a large AC voltage, transformed it in to a smaller AC voltage using a transformer, and rectified this voltage so that it is of one polarity regardless of the input voltage. Next, we added a capacitive filter to smooth out the ripple in the voltage which improves the output voltage waveform. A circuit of the power supply components we have added thus far is shown below in Figure 5.

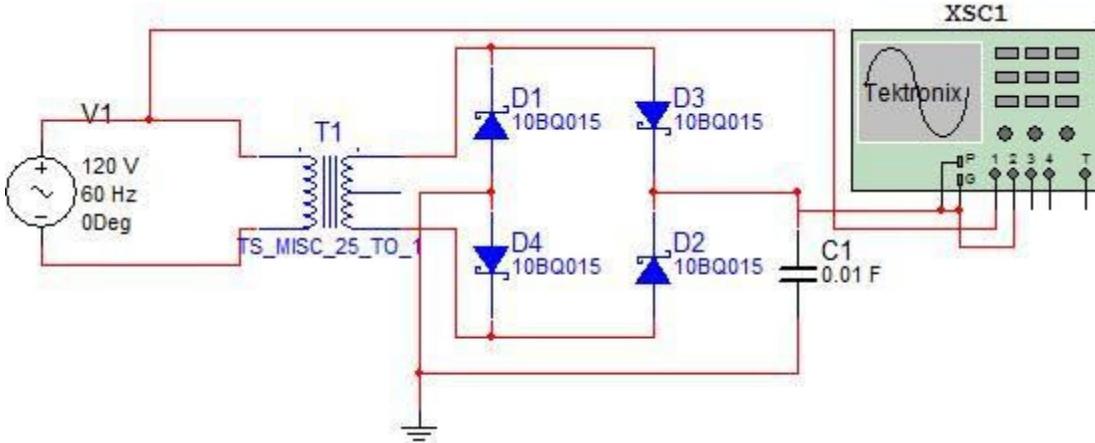


Figure 5: Power Supply circuit with filter capacitance shown.

In order to decrease the ripple voltage across it, the size of the capacitor was chosen to be large (in the order of several microfarads). In order to calculate the ripple voltage across a capacitor, we can use a simple equation: $dv/dt = I / C$ with dv/dt = change in voltage with respect to time, I = DC load current, and C = capacitance. For 60 Hz power lines, $dt = 0.008$ seconds. Let's say we chose to use a capacitor with a value of 20,000 microfarads with a current of 1 amp; then our ripple voltage is calculated as follows:

$$dv = \frac{I}{C} * dt$$

$$dv = \frac{1}{0.02} * 0.008$$

$$dv = 0.4 \text{ volts}$$

Using the typical voltage of 115V from the primary, our secondary voltage is calculated at 5.5V AC. Thus, the peak voltage is $1.41 * 5.5\text{V}$ or 7.7V. If we subtract 1 volt for the bridge rectifier (schottky), and 0.40 volts for the ripple voltage we just calculated, we are left with 6.3 volts DC going into the voltage regulator. Since this is about 1.3 volts above the desired 5 volt output, we are okay.

2.2.1.5 Voltage Regulation

For our project, we must be sure we maintain a constant voltage level of 5 volts. To do this, we added a voltage regulator to our power supply. Just like the majority of the items in our project, we were careful in choosing a voltage regulator. We needed one with a low input to output voltage drop. One of the voltage regulators we looked into was the LP3872ES-5.0. The typical application of this type of voltage regulator is shown in Figure 6 below.

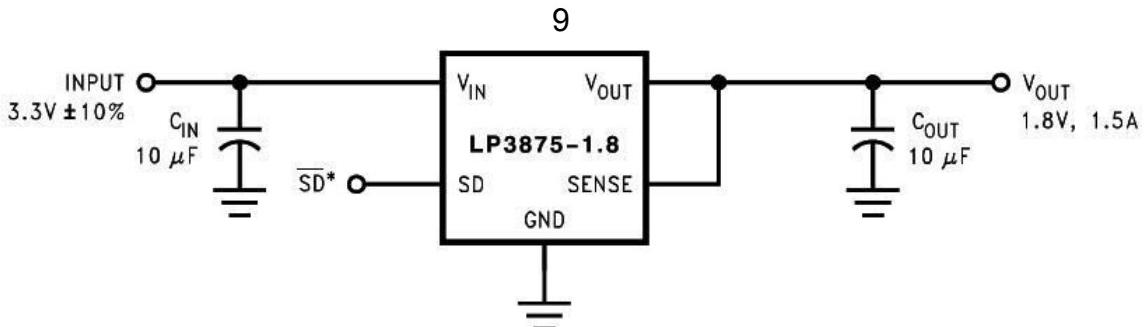


Figure 6: Typical application of a LP3872ES-5.0 voltage regulator (Image used with permission from National Semiconductor.)

This part is ideal for low-voltage microprocessor applications such as the DLLF since it has an ultra low dropout voltage, responding quickly to step changes in load. However, just like any low drop-out voltage regulator, the LP3872ES-5.0 requires external capacitors for stability. Proper performance is directly proportional to the correct selection of these capacitor values. When choosing capacitors, we always pay careful attention to the breakdown voltage rating, choosing capacitors with a voltage rating higher than the highest voltage the capacitor will ever experience during circuit operation. For instance, according to the voltage regulator specifications, the chosen input capacitor is at least 10 microfarads. The output capacitance equals at least 10 microfarads as well but it is also placed no more than 1 cm. from the device and connected directly to the ground and output pins, both with zero current flow. We also considered the material with which the capacitor is made. We made sure the required capacitance is provided over the entire temperature range during operation. The capacitance of a Tantalum capacitor varies little with temperature while ceramic can vary quite a bit. So, it is recommended that, for this type of voltage regulator, we use a solid Tantalum capacitor for the output.

A continuous current of 1.5 amps is delivered from this voltage regulator. However, as we found in the data sheet provided by National Semiconductors, it may require the use of a heat sink depending on the maximum ambient temperature and maximum power dissipation of the application. We must keep the junction temperature within the range specified under operating conditions. The total power dissipation of the regulator is equal to: $PD = (VIN - VOUT) IOUT + (VIN)IGND$ where $IGND$ is the operating ground current of the device (14-15mA for a 1.5A load current and 9-10mA for a 150mA load current). A heat sink rated for approximately 5 watts of dissipation would be sufficient. This voltage regulator can be purchased from Digi-Key for approximately \$3.25.

Now, the size of our voltage regulator depends on how many components we need to provide power to in our project. We originally planned on using only three LEDs and one nozzle for our fountain. If this were the case, we would only need 1050mA if all three of the LEDs were turned on at one time plus the current draw from the microcontroller. However, to make the fountain more aesthetically pleasing and similar to other fountains of this type on the market today, we will

use two sets of LEDs and two nozzles. So, the current draw will jump to 2100mA if all six LEDs were on at one time (to make a white color). As a result, the simplest way to modify our power supply is to add a different voltage regulator, perhaps one rated for at least three amps rather than only one and a half amp as originally planned. There are several options on the market today; one of them manufactured by Micrel, Inc, manufacturer part #MIC29300-5.0WU. This is a linear five volt voltage regulator with an output current of three amps, using only two capacitors for operation. As we found from the Micrel, Inc. datasheet, this regulator has low dropout voltage, a wide range of input voltages, low ground current, an extremely fast transient response, reverse battery and “load-dump” protection, and an accurate 1% guaranteed tolerance. More specifically, the characteristics of this voltage regulator are as follows: maximum input supply voltage (V_{in}) = -20V to +60V; maximum enable Input Voltage (V_{en}) = -0.3V to V_{in} ; maximum power dissipation – internally limited; typical dropout voltage: 370mV. The typical application of this voltage regulator is shown below in Figure 7.

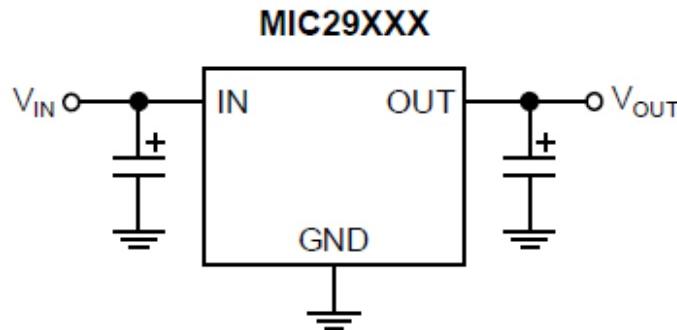


Figure 7: Typical application of a Micrel, Inc. MIC29300 series voltage regulator (Image used with permission from Micrel, Inc.)

By choosing a voltage regulator with a higher current rating, we are guaranteeing that our project will be able to run as planned, even if we decide to add additional LEDs, nozzles, etc. The 5V, 3A regulator from Micrel, Inc. can be purchased from Digi-Key Corporation (part # 576-1122-ND) for \$5.45 and from Newark for \$5.68.

In order to properly apply a voltage regulator to our circuit, we considered adding a heat sink. The thermal characteristics of a voltage regulator are perhaps the most complex to analyze with the key points being output voltage, output current, maximum ambient temperature (T_A), and input voltage. Basically, we calculate the power dissipation of the regulator and then the heat sink thermal resistance. Without a heat sink, we have to calculate the junction temperature to find the maximum allowed power dissipation without exceeding the maximum junction temperature of the regulator. All of the preceding calculations are discussed in the design section and can be found on the datasheet for the Micrel MIC29150/29300/29500/29750 high-current, low-dropout regulators. However, the voltage regulator datasheet does suggest a heat sink rated for 5 watts of power dissipation. One heat sink that would work for our project can also be found at Digi-Key and is manufactured by Wakefield Thermal Solutions, part

number 527-24AB-MS4-ND, with a price of \$6.44. This heat sink is ideal for DC to DC converters such as the one we require for our project. When ordering the part number, it comes as a package including a hardware kit with everything needed in order to mount it to our voltage regulator to keep the regulator cool.

2.2.1.6 Switched-Mode Power Supply Option

At this point, we decided to look into another type of power supply option, the switched-mode power supply or SMPS. Unlike the linear power supply, the switched-mode power supply utilizes a switching regulator in order to provide the desired output voltage. When compared to the earlier block diagram of a liner power supply, the general block-diagram of a switching power supply shown in Figure 8 below is more complex.

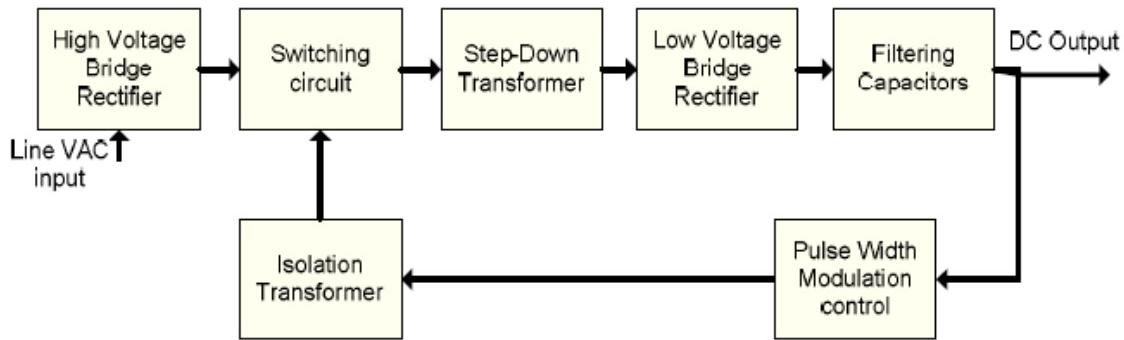


Figure 8: General structure of a switched-mode power supply

While the linear power supply consists of only a transformer, bridge rectifier, filtering capacitors, and a voltage regulator, the switching power supply consists of both a high and low-voltage rectifier, two transformer stages, filtering capacitors, a switching circuit, and a pulse width modulation control circuit.

In a SMPS design, the energy flow is directed by power semiconductors operating at a high frequency constantly switching on and off. The switches are providing the transfer of electrical power through energy-storing components such as inductors and capacitors (Rozenblat, 2003). The main advantages of a SMPS are higher efficiency, smaller size, and lighter weight. Since the energy flow is being controlled by a switch, there are very little losses. When the switch is off, the flow of current is blocked, and, when the switch is on, it sees a low voltage drop and any current that is flowing through it will pass. Since power dissipation is defined as the product of current and voltage, both the on state and off state of the switch is very efficient, producing very little loss in power (Rozenblat, 2003). A smaller amount of heat is generated due to the reduced size of the passive components and so the total size of this type of power supply is much smaller than the traditional liner power supply. Efficiency for the SMPS is generally 70-90% while a regulated linear power supply is traditionally only 50%. A comparison of the two is shown below Figure 9.

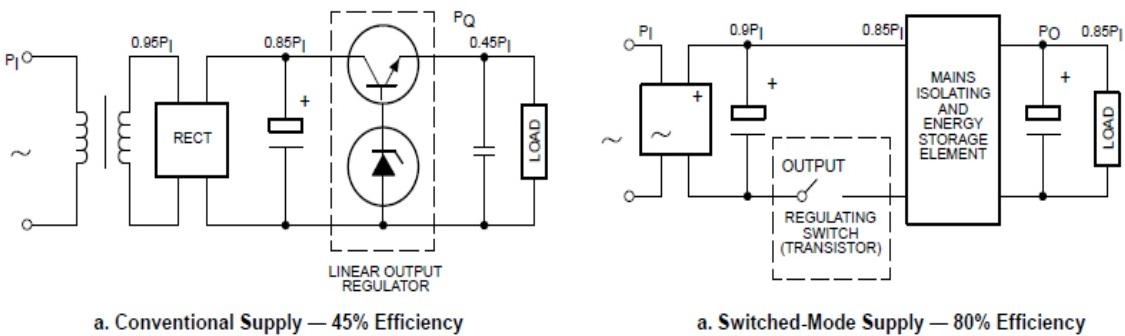


Figure 9: Comparison of a Linear versus Switched Mode Power Supply

The biggest disadvantage of the switched mode power supply is that it is not easily built and utilized by electronics hobbyists because it has more complex circuitry (Purdie, 2003). So, while the efficiency is ideal for applications where higher power is needed, it is probably not necessary to design and build a switched mode power supply for our DLLF.

2.2.2 System Control

In researching the system control, we concentrated on ease of use and cost as our priorities. Because of the simplicity of the tasks required to be completed by the system control, we narrowed down our research to include only microcontrollers. A microcontroller is considered a self-contained system with a processor, memory and peripherals and can be used with an embedded system. The system control portion of our project is in essence an embedded system. Once programmed and installed on our PCB, we will not need to have any interaction between the user and the system control. There are a vast number of microcontroller manufacturers, Motorola, Freescale, Atmel, Microchip, and Texas Instruments, just to name a few. Because of this, we needed a way to narrow our search to only a handful of manufacturers or microcontroller families. Upon suggestion from our advisor, we decided to look at Atmel, Motorola, and Microchip microcontrollers. We need a microcontroller that is able to hold 4 small user programs. The microcontroller we choose must have enough user I/O pins to handle the following inputs and outputs: 6 pins for the automated program selection 1 manual cutter control, 1 pin to monitor the water level, 1 pin to monitor the IR remote control, 1 pin for the day/night sensor, 1 pin for the motion sensor, 1 pin for initiating manual control of LEDs, 6 pins for LED manual on/off, 1 pin for the external oscillator (for IR remote control), and 1 pin for the color organ. The microcontroller must also be able to drive the 6 LED driver outputs as well as 2 Pulse Width Modulated outputs to drive the Cutter arm. There will also be 1 output for the pump controls.

We originally thought that using the Motorola 68HC11 would be a good use of our knowledge from Embedded Systems. We already know the programming syntax and we are familiar with the interface on the evaluation board. This would

give us an edge to developing the software and may help to relieve some of the stress we would encounter while trying to learn a new programming syntax for developing our fountain. The 68HC11 has a total of 26 I/O pins. So although the ease of programming this chip is a benefit, we are unable to use it because we need at least 30 I/O pins.

Next we looked at the Atmel Microcontrollers. Atmel has 9 different Microcontroller subcategories which can be used for many purposes. The Atmel ATmega1284P is a 40-pin DIP, which would allow for easy installation versus the surface mount parts. The ATmega1284P will run off of 3.3 to 5.5V, this fits the criteria we desire for our PCB assembly. Atmel microcontrollers can be programmed in either C code or using Assembly language. Atmel offers the software AVR studio 4 free for download; this program allows you to program any of the Atmel microcontrollers. These microcontrollers are available through many distributors, but the cost ranges from about \$5.00 to \$13.00. While navigating the Atmel website, we found it difficult to compare the various types of microcontrollers they manufacturer, this was a bit of an inconvenience. We also had hard time finding information about the software for programming without downloading the package. Because of the slightly higher prices and inconvenient web site, we decided to keep looking for other options for our project.

Next, we looked at Microchip. Microchip offers 8-bit, 16-bit and 32-bit microcontrollers. For this project we only need an 8-bit microcontroller that narrowed the search to PIC10, 12, 16, or 18.

As you can see above, the PIC10 family contains no Interrupts. We are using interrupts for driving the LED's. We do not have power consumption restrictions so we aren't taking battery operated enhancement into consideration. In order to hold all the programming, we would like to have more than 10Kb of program memory; therefore we are excluding the PIC10 family from our selection. The midrange architecture seems to be the most beneficial to our application. Although the PIC18 is the most robust architecture by putting this family into our PCB we would be using a part too complex for our application.

Once we decided on a PIC16 series microcontroller we compared the number of I/O pins and A/D's. In order to allow for more flexibility we chose the 877; this increases the number of A/D and I/O pins. This will allow us to keep the option open to increase the functionality of our fountain. The PIC16F887 microcontroller has only 35 programming instructions, and has 35 I/O pins. The small number of instructions will allow for a smaller learning curve compared with some of the more complex microcontrollers on the market.

In choosing a microcontroller it was important to understand the different packaging standards and the differences they would make in designing our PCB. The microcontroller we chose came in 3 different package types, the 40-pin PDIP, 44-pin QFN and 44-pin TQFP packages. The PDIP is the Plastic Dual In-Line, this packaging is meant for through-hole mounting. The QFN is Quad Flat No Lead packaging; this packaging is advantageous because it allows for lower

lead inductance and a smaller sized chip area, but it may be more difficult for us to use due to the mounting process used for this package. The TQPF is similar to the QFN, but this package contains surface mount leads distributed along the outer surface of the chip with 11 pins per side. Although all package types have their benefits, we will be using the PDIP. In order to control costs, the PCB we are having fabricated will have only through-hole mountings; this PDIP packaging is the only package with a through-hole mounting style.

The PIC16 microcontroller requires software to program the chip. Also, in order to communicate with the chip, we need some type of interface between the programmer and the chip. We chose to look for a development board that would allow for easy program upload. The development board we chose to purchase is from Futurlec. This development board comes with all the necessary equipment for programming the PIC. Choosing this option allows us to begin program development and testing before the PCB is complete. PIC microcontrollers can be programmed using either assembly, or C compilers, discussion of these programming methods will be discussed in section 2.3 Software.

2.2.3 LEDs

The Dynamic Liquid Light Fountain includes design for LED (or Light Emitting Diode) lighting when the fountain is operating in the dark or when operating after turned on by the motion sensor. LEDs have many benefits over other traditional lighting sources such as their compact size, lower energy consumption, faster switching ability, and lower power consumption. In fact, they are approximately three times more efficient than incandescent lamps (Arnold 2006). The disadvantages of LED lighting over traditional lighting include higher cost, difficulty in locating the type of LED required, increased sensitivity to heat which leads to lower life span and less efficiency, and output limited to one direction at a narrower angle.

The first LED was designed and built in 1920 by a radio technician named Oleg Vladimirovich Loser that noted diodes used in early radio receivers emitted a light when current ran through them. The LED wasn't introduced as a practical electronic device until 1962. The LEDs can have different color lights placed in any formation to create designs and images. Almost all early devices emitted a low-intensity red light, but as modern LEDs have been developed there is a wide array of almost any color desired including ultraviolet and infrared wavelengths, with a wide array of brightness.

The general operation of a LED can be described easily as they are based on the semiconductor diode; when they are switched on, or in forward mode, holes and electrons are able to recombine which results in a release of energy in the form of light (Arnold, 2006). The size of the energy gap in the semiconductor determines the intensity of the light emitted. The material of the junction of the LED also determines the light it emits. Blue, white, true green, and UV types of LEDs consist of Indium gallium nitride (InGaN), while yellow, red, and orange LEDs are made out of Aluminum gallium indium phosphide (AlGaInP or AlInGaP)

(Arnold, 2006). Basically, the more LEDs we connect to our circuit, the brighter and more dynamic our light show can be.

The majority of indicator LEDs specify their characteristics at a current of 20mA with a typical forward voltage of 2-4 volts DC. However, illumination LEDs, such as the ones we are using in our project, usually have larger junctions and can draw more current, using more power and providing a brighter output. A standard drive current for a high power LED is 350mA and will dissipate around 1watt of power. Another thing we need to examine is the reverse voltage of the LED; it will conduct current when a forward voltage is applied but not necessarily when a reverse voltage is applied. We must also verify that the reverse voltage does not exceed the rating of the LED, because, if it does, the LED may fail. To be safe, we can design the circuit to provide a 15mA current through the LED. This way if there are unaccounted for voltage/current variations, excessive heat build-up in the circuit, or if there is a mounting issue, the LEDs will still work properly. The following table, Table 1, summarizes the typical characteristics of each of the LED's we will be using in our DLLF project. These particular numbers are for Digi-Key part number 754-1330-1-ND which is a high-brightness 3 watt RGB LED manufactured by Kingbright Corporation and can be purchased for \$8.16. All ratings are based on an ambient temperature of 25 degrees Celsius.

Digi-Key Part #754-1330-1-ND	<u>Red</u>	<u>Green</u>	<u>Blue</u>
Current (mA)	350	350	350
Peak Forward Current (mA)	500	500	500
Forward Voltage, Average (V)	2.5	3.3	3.2
Power Dissipated (W)	1.05	1.33	1.25
Thermal Resistance (°C/W)	12	9	9

Table 1: Typical characteristics of a high brightness LED

On the other hand, rather than using a combined LED such as the one we found at Digi-Key, we could have also use three individual LEDs, one red, one green, and one blue, all with similar characteristics. By purchasing the LEDs individually rather than as a combined unit, we would have spent more money since they were anywhere from \$5 to \$8 a piece.

After meeting several times throughout the semester, we decided to add another set of three RGB LEDs to our project. Thus, we have six I/O pins on the microcontroller dedicated to the LED drivers, with one LED per driver. Three of the LEDs illuminate one of the nozzles while the other three light up the second nozzle. Each set of LED lights consists of one red, one green, and one blue LED or we can choose to purchase two RGB LED lights. The only issue with that is that we weren't able to find them in a through-hole mount style. They are surface mount with didn't coincide with our original design. We are able to either set it up

so that the nozzles are both simultaneously lit up with the same color(s) at the same time or so that they are both illuminated separately. This is done by choosing the correct program in the microcontroller using the remote control. We also added manual control switches that allow the user to choose which colors are illuminating which nozzle. This will all be discussed later in our paper. However, since we have decided to set the project up this way, we thought we would purchase individual LEDs. These LEDs will be through-hole mount in order to make the PCB design easier. After considering all of the requirements of our project we researched LED prices at Digi-Key as follows: \$4.79 each for red, \$6.04 each for blue, and \$6.04 each for green. However, after considering the function of the LEDs and how we would transfer the light to the nozzle via fiber optic cabling we decided to purchase the RGB combined LEDs. We found them on ebay for \$45 for a set of 5, keeping in mind that we would be testing them. This way we had extra just in case something unforeseen happened.

In order to power the LEDs, we built six LED driver circuits. Many such circuits exist and there are many variations to each circuit depending on the type and size of the LED being used, the lighting requirements of the project, the voltage provided by the power supply, which microcontroller is being used, etc. Since we are using a 5 volt DC power supply, we based our circuit off of 5 volts. We also will be using the PIC 16F887 microcontroller to deliver a signal which will choose which LED should illuminate and for how long. Each LED is connected to an output pin of the microcontroller. In a future section, we will also discuss our addition of a color organ to our DLLF. Once the microcontroller recognizes that there is a valid audio signal, it will switch to the program that illuminates each LED based on the frequencies of the audio signal. This type of display is found on Christmas trees and on other indoor and outdoor lighting displays.

2.2.4 LED Drivers

When driving LEDs most people will suggest that you use a current limiting resistor in order to protect the LED. However, this is not something that is required, only recommended. Since an LED is a diode, its current-to-voltage characteristics are not linear, creating a tricky relationship for any circuit designer. A certain forward voltage is required in order to turn on an LED and before that voltage is reached, there isn't a noticeable change in the current. However, as soon as that forward voltage is reached, there is a noticeable change in current which then lights up the LED. From this point forward, small changes in the voltage result in large changes in the forward current. As with any other electrical component, when choosing LEDs it is imperative that we choose an LED with an appropriate forward current for our design. We don't want to exceed that current or we may destroy the LED. So, if we place the LED close to the power supply voltage, the high current would immediately destroy the pn-junction, which is where the current limiting resistor comes into play. A current limiting resistor is placed in series with the LED in order to dissipate any current in excess of that needed for the LED to work correctly.

For example, if we choose an LED with a forward voltage of 2.1V, a maximum current rating of 25mA, and use it with a 5V power supply such as the one we are using for the DLLF, we would need a resistor to dissipate the remaining 2.9V. In order to compute the size of the resistor, we must use the standard power equations below:

$$R = \frac{V}{I} = \frac{(5 - 2.1V)}{25mA} = 116\Omega$$

Of course, to be safe, we would use a resistor with a value of 120-150 Ohms, ensuring that we are not driving the LED near its maximum rating. Now, we need to look at how much current is coming out of the I/O pin on our microcontroller. According to the data sheet of the microcontroller, the maximum current sourced by any I/O pin is 25mA. So, if we choose 20mA (slightly less than the maximum), we need to then take a look at the LED I-V curve and find the voltage, which, for in this example, is 2.0V. Now, we must recalculate the resistor as follows:

$$R = \frac{V}{I} = \frac{(5 - 2.0V)}{20mA} = 150\Omega$$

If we choose a 150Ω resistor, we must now find its power dissipation as follows:

$$P = V * I = 3V * 20mA = 60mW$$

Here, it is desirable to choose a resistor that is rated at $\frac{1}{4}$ Watt and has a value of 150 Ohms. We do this for each LED since all have unique current to voltage characteristics.

Now, in order to save cost and to reduce the number of components on the PCB, we could have chosen not to use current limiting resistors in our LED driver circuit. We would do this also to reduce the amount of energy we are wasting since the resistors will create heat. One way to do this would be to lower the input voltage and make it closer to the forward voltage of the resistor. Another way is to use Pulse Width Modulation (PWM). By switching the LED fast enough, the observer is unable to see it turning on and off, creating an illusion that the LED is on all of the time. Although we originally thought we would use PWM for the LEDs, after reviewing the functionality of our LED programs, we are not going to do so. We were going to use those I/O pins specified for PWM in order to drive the cutter mechanism but, after further review, we decided to use a different circuit which will be explained in more detail further on in the paper.

One of the simplest and most inexpensive ways to provide power to a LED circuit, and the way that is recommended by most, is a constant current source. Typically, it consists of a small integrated circuit and several other outside components. The result is a constant current supplied to the LEDs no matter what type of input voltage exists or what type of forward voltage drop the LED has, which is especially important to consider when using high-power LEDs such as the ones we are using for the DLLF. Shown below in Figure 10 is a basic

constant current source hooked up to a microcontroller, similar to the set-up we will be encountering with the DLLF.

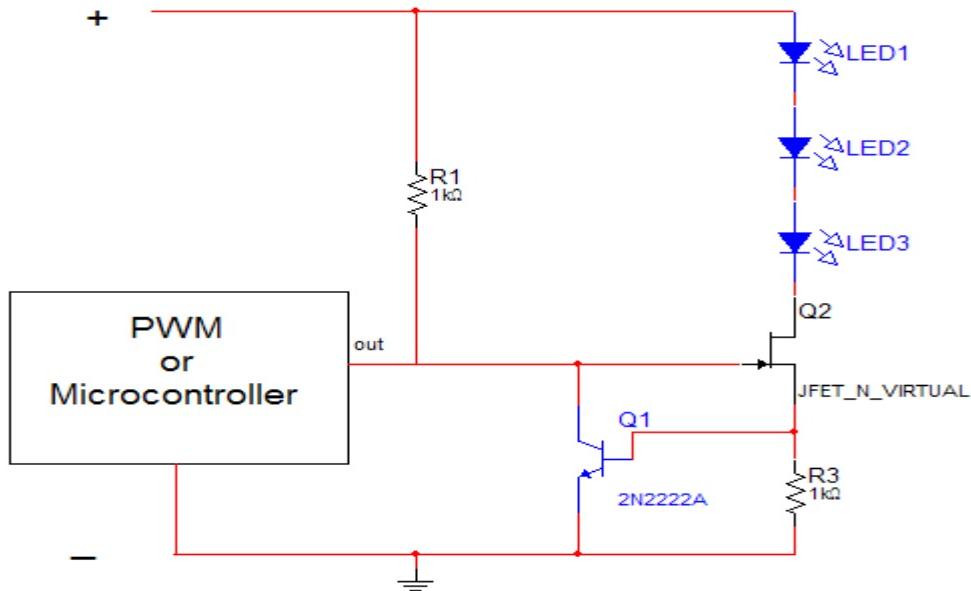


Figure 10: Typical constant current source with microcontroller

This circuit uses Q2, which is a power NFET as a variable resistor. This transistor starts out turned on because of R1. Q1, which is a small NPN transistor, is utilized as an over-current sensing switch with R3 assigned as the “set resistor” or the “sense resistor” which will trigger Q1 when there is too much current flowing.

When examining where the main current flows, we can see that it flows through the LEDs first, then through Q2, and finally through R3. If, at any point in time, there is a surplus of current flow through R3, then Q1 will turn on which will in turn trigger Q2 to shut off. When Q2 turns off, the current flow through the LEDs is reduced along with the current flow through R3. This type of configuration is generally called a “feedback loop,” and its purpose is to continuously monitor the current through the LEDs. If the current is too high, it will compensate automatically, protecting the LEDs and the rest of the system. Thus, a constant current is supplied to the LEDs at all times, resulting in optimal operation.

Other parameters of this circuit include the high resistance of R1. When Q1 begins to turn on, R1 is overpowered. Here, Q2 is performing just like a “perfect” resistor, ensuring that the correct current is flowing through the LEDs. As far as excess power, it is being dissipated in Q2. The main downside to this circuit is that we need to be sure to configure the LED string (or single LED) so that it is very close to the power supply voltage. It is not critical that we do this, but, if we don’t, we are certain to waste some power.

To set the current, we can use the following calculations:

$$LED\ current = \frac{0.5}{R3}$$

$$R3\ power = \frac{0.25}{R3}$$

In order to prevent R3 from getting too hot, we should select a resistor value at least two times the value of power we calculated. So, if we are using a LED with a current of 350mA, we should come up with the following values:

$$LED\ current: 350mA = \frac{0.5}{R3}$$

$$R3 = 0.175 \Omega$$

$$R3\ power = \frac{0.25}{0.175} = 1.43\ watts$$

From these calculations, we can determine that we will need a resistor rated for at least 1.5 watts and the closest standard resistor value to 0.175 Ω .

The parts used for this constant current source can be summarized in Table 2 below.

Item	Size	Type/Rating
Q1	Small	NPN
Q2	Large	N-channel
R1	$\frac{1}{4}$ watt	100k Ω
R3	1 watt +	n/a

Table 2: Specifications for parts needed to build constant current source

The limitations of this circuit are largely due to Q2, the NFET. This transistor limits the circuit in two ways:

1. Since Q2 acts as a variable resistor to meet the need of the LEDs by stepping down the voltage from the 5V power supply, we need to look at the power it dissipates. We will need a heat sink if there is a major difference in the power supply voltage with the LED voltage or if there is a high LED current. Q2 power is equal to the total number of dropped volts plus the LED current. Only about 2/3 watt of power should be applied to Q2 if we choose not to use a heat sink.
2. Since the “G” pin on Q2 is rated for 20 volts, this could normally be an issue due to the fact that this variation of a constant current source can be used for input voltages ranging anywhere from 3 volts to 60 volts. However, since we will not be using voltages above 20 volts, this isn’t a concern to us. In fact, we will be connecting the circuit to a microcontroller

and so we may want to add a zener diode (4.7 or 5.1 volt) so that the G-pin voltage is set to about 5 volts.

Lastly, we need to be sure that we choose Q1 so that it is of very little sensitivity to heat since the current set point is slightly sensitive to temperature. One that is recommended is Fairchild 2N5088BU. However, even if we use this part or one that is similar, we should still expect to see approximately a 30% reduction in current set point in the range of -20C to +100C. The good thing about this is that it could protect our LEDs from overheating.

Our proposed circuit including all three color LEDs is shown in Figure 3 below. Note that there are 6 LED drivers operating off of six of the microcontroller I/O pins. These lights will turn on and off based upon the programs created in the microcontroller, including a color organ.

Another set-up for the LED driver is shown in Figure 11 below. Also shown are the switches we are implementing which, depending on whether each one is on or off, signal to the microcontroller the appropriate program to run to light up the LEDs.

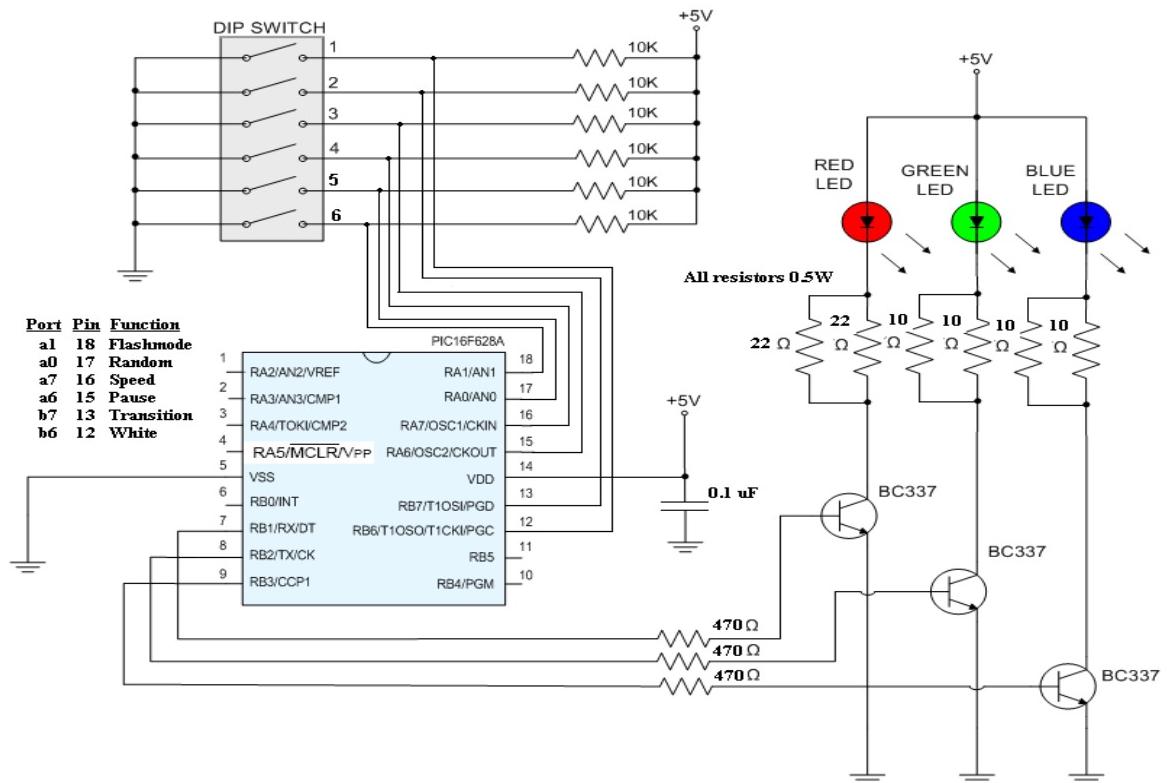


Figure 11: An additional configuration to drive our LEDs.

Another option we considered was to purchase drivers already on the market. These drivers maintain a specific output current by varying the output voltage. They are utilized best in applications where pulsing or flashing of the LEDs is

required. They also require no additional resistors or a heat sink. After doing some research, one such driver is the 3021 and 3023 BuckPuck LED Power Module. They are applied to LED circuits as shown in Figure 12 below:

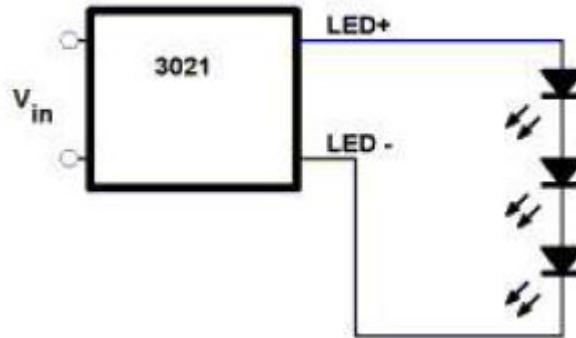


Figure 12: Example of a manufactured LED driver application (Image used with permission from LuxDrive)

The advantage of using one of these existing drivers is that our LED is guaranteed to light up since the circuitry inside the driver has already been tested against specifications. These are also through-hole PCB mounted which fits into the design of our project. However, the disadvantage is that these are relatively expensive, especially since we only need one driver to light up one LED (since we want the LEDs to light up at different times based on color). Since these cost approximately \$13.99 each from ledsupply.com, this option would have been rather expensive. If we were lighting up a string of 12 LEDs for each color, however, this would probably have been a more efficient way to go.

2.2.5 Color Organ

Originally, we hadn't considered adding a color organ to our project. However, after submitting our initial documentation, it was highly recommended that we do so. A color organ is a device that converts an audio signal into rhythmic light. This is similar to a light organ but a light organ does not use different colors to represent the audio signal. Instead, it varies the brightness of one particular color of light based on the intensity of the input signal; the higher the sound, the brighter the light and vice versa. Since our preference was to have more than one color illuminating our fountain, we designed a color organ, which works by detecting the various frequencies in the sound medium. Based on the configuration of the device, it represents each different band of frequencies with a certain color of light. For example, an audio signal is represented by red light for the highest frequencies, green light for the middle frequencies, and blue light for the lowest frequencies. Now, our DLLF appears to "dance" to the sound of any type of music played!

There are many options for receiving input for our color organ. We can either attach a device such as an MP3 player, iPod, or computer directly to the

microcontroller (after passing through a few amplification stages of course) for spectrum analysis or we could have designed the color organ to pick up any desired sound using a microphone. The advantage to using a direct input such as an iPod is that the device only displays colors based on the audio signal whereas if we used a microphone, all other types of recognizable sound would be depicted such as voice, background noise, and miscellaneous noise. The advantage of using a microphone is that the user will also be able to hear the noise at the same time the lights are dancing to the noise. If we directly connected the audio input, this would not be possible. Thus, after careful consideration, we decided to use a splitter to divert the signal both to the microcontroller color organ circuitry and to a set of speakers. This way, the user is able to hear the music at the same time he/she can see the lights “dance” to the music.

The main operation of a color organ begins with an input signal. After the input signal, we added an in-series capacitor to couple in the input. This way, only the AC signal is transferred from one circuit to the next, blocking the DC signal. The DC bias settings of the two coupled circuits can be isolated. Next, this signal is sent in to a dual operational amplifier for isolation and amplification. First, there is an isolation amplifier to provide an electrical safety barrier while providing electrical isolation. If an isolation amplifier were omitted from the design, excessive noise would be present and sometimes instrument destruction can occur. Then, we provided amplification of the signal before it can be applied to the microcontroller. One such amplifier that we looked at using is the LM1458 dual operational amplifier by National Semiconductor. These two amplifiers share power supply leads and a common bias network; otherwise they operate completely independent of one another. Some of the features of these amps are as follows: short circuit protection, no frequency compensation required, wide common-mode and differential voltage ranges, and low power consumption. Some of the characteristics that are important to us were found in the specifications by National Semiconductor and are shown in Table 3 below.

Dual Operational Amplifier Features	LM1458	LM1558
Max Supply Voltage	$\pm 18V$	$\pm 22V$
Power Dissipation	400mW	500mW
Operating Temp Range	$0^{\circ}C - +70^{\circ}C$	$-56^{\circ}C - +125^{\circ}C$
Input Offset Voltage	Typ: 1.0mV, Max: 6.0mV	Typ: 1.0mV, Max: 5.0mV

Table 3: Important characteristics of a dual operational amplifier

Comparing the values of the components of this amplifier, we can see that the main difference is the operating temperature range. Once the signal has left the isolation amplifier, we obtain an output voltage by installing a resistor for the output current to run through. Then, the signal enters the amplification stage.

We are utilizing a $50\text{k}\Omega$ potentiometer for gain control in the feedback loop of our gain pot. As we've learned in our electronics classes, the most important equations to consider when constructing an inverting operational amplifier are listed as follows:

$$V_- \approx V_+ = 0$$

$$I_{in} = \frac{V_{in}}{R_{in}}$$

$$V_{RF} = R_f \times I_{in} = V_{in} \frac{R_f}{R_{in}}$$

$$V_{out} = -V_{in} \frac{R_f}{R_{in}}$$

Once we have converted the signal into a form the microcontroller can work with, we are applying the signal to an input pin of the microcontroller; the microcontroller takes each input signal, manipulates it so that it falls into one of three categories (low band, mid band, high band), and then sends an output signal to the corresponding output I/O pin to light up a particular LED. We constructed a basic color organ circuit based on the aforementioned conditions and it is presented in Figure 13 below:

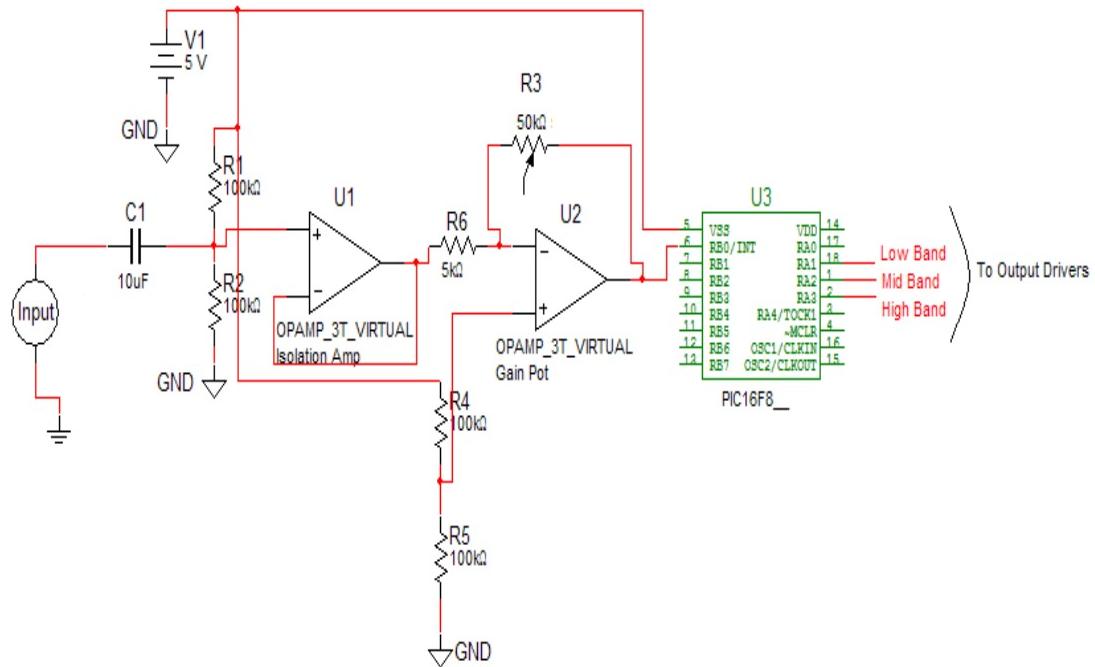


Figure 13: Typical configuration of the color organ.

When constructing this circuit in Multisim, our microcontroller was not listed so we chose one similar to the PIC16F887, however the particular microcontroller

shown does not have as many I/O pins as the one we are using. Again, this is just a basic diagram showing the components that were already discussed and a building block for us to use when designing the color organ. Aside from the power supply, microcontroller, and LED drivers, the specific parts we used to build the color organ are summarized in Table 4 below:

Item	Size	Quantity
Resistor	100kΩ	4
Resistor	5 KΩ	1
Dual Op-Amp	n/a	1
Capacitor	10μF	1
Potentiometer	50 KΩ	1

Table 4: Components required to build a color organ

Another option we considered for the color organ was to operate it independently of the rest of the circuitry. In other words, we could have used something referred to as a three-channel spectrum analyzer in order to illuminate the DLLF. A spectrum analyzer would have allowed us to bypass the microcontroller and keep the signal in the analog form. Taking the audio signal from the input, we would have run it through three filters. In order to set the desired frequency range for each LED color, we would need to add a 22k potentiometer before each amplifier. Potentiometers provide an adjustable voltage divider and are three-terminal resistors with a sliding contact. They are used often in audio circuits for volume control and amplification, adjusting the loudness, frequency attenuation and other aspects of the audio signal as desired by the user. A sample design of a three-channel spectrum analyzer we considered implementing in our project is depicted in Figure 14 below:

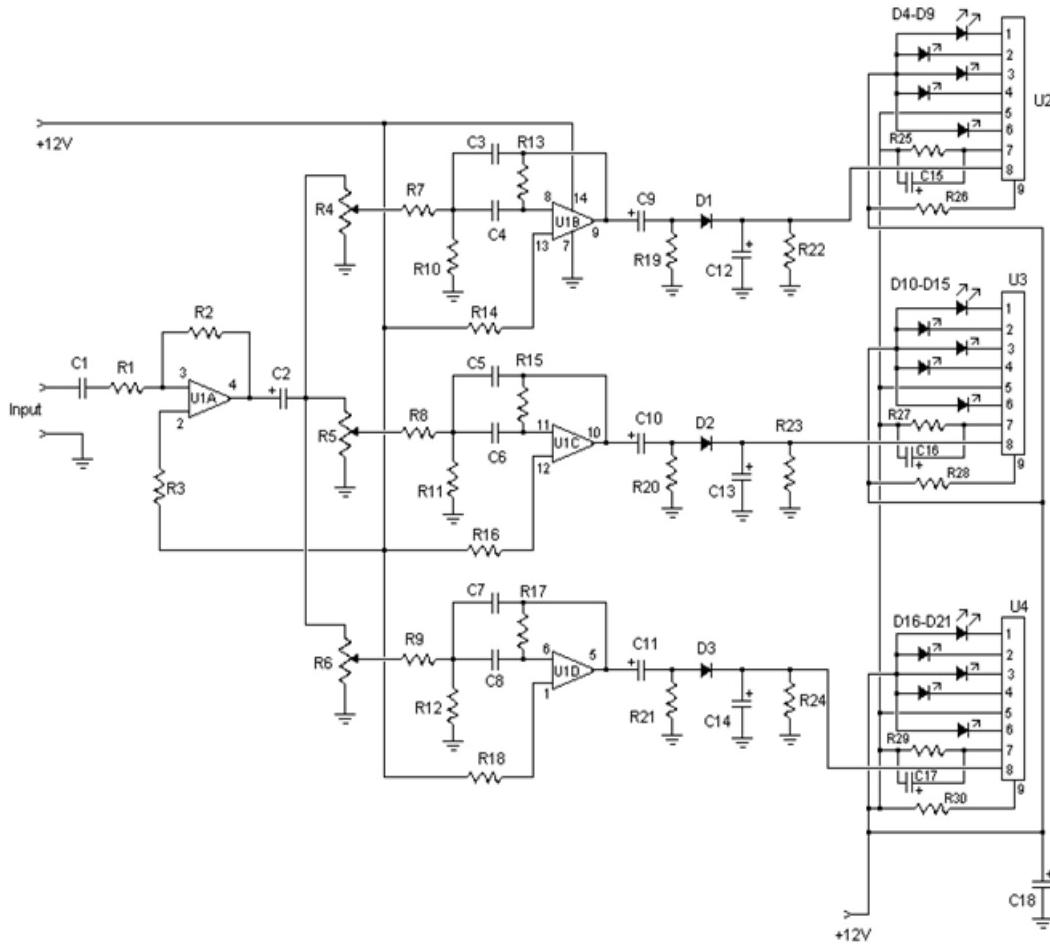


Figure 14: A three-channel spectrum analyzer with LED displays

As previously stated, the advantage to this type of design is that the bulk of the circuitry would be separate from the microcontroller, which would allow for easier testing and trouble shooting. However, the disadvantage is that the user isn't able to control the LEDs through the remote. Also, since we have switches for the user to manually control the LED programs and these switches are interfaced with the microcontroller, we would have needed to find a way to connect the LEDs to the microcontroller separate from the audio input. Considering all of these facts, we decided that this type of design would cost more money and time to implement.

2.2.6 IR Remote Control

There are two major protocols used in infrared remote controls, RC-5 and NEC. The RC-5 protocol was developed by the Philips Company in the late 1980s. It has been implemented by most American and European manufacturers of consumer electronics. NEC protocol is largely used by Japanese manufacturers. Each protocol has its own advantages. The advantage of the NEC protocol is that each brand is assigned its own header and is free from interference from

another brand's remote. The advantage of the RC-5 protocol is that any remote used to control a particular type of device, i.e. a television, can control any other television using the RC-5 protocol.

For ease of programming and availability of resources, we chose to use the RC-5 protocol for our project. The RC-5 protocol uses bi-phasing modulation on a carrier of 36 KHz. All bits of the infrared pulse have an equal duration, 1.778 milliseconds. Half of the bit time is filled with a burst of the carrier and the other half is idle. A logical 1 is represented by the first half of the bit time being idle and the second half filled with the carrier. A logical 0 is represented by the first half filled with the carrier and the second half is idle. Each command utilizes fourteen bits as depicted in Figure 15 below. The first bit is the start bit which is always logic 1 to allow the receiving IC to set the gain. The second, or field bit, denotes whether the command sent is in the lower field (logic 1 = 0 to 63) or the upper field (logic 0 = 64 to 127). Third bit is the control bit, which toggles with each button press. This allows the receiver to distinguish between subsequent button presses. The next five bits are used for the address that selects one of thirty two possible systems. The final six bits are the command bits, which represents one of the possible 128 commands.

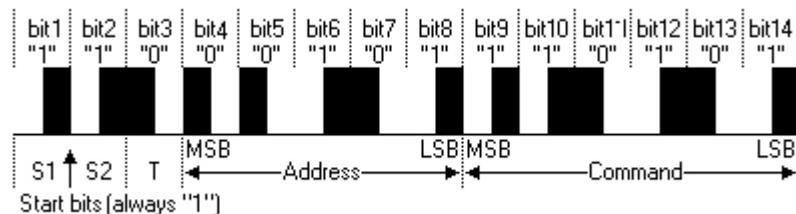


Figure 15: RC-5 Protocol Pulse Train (Image used with permission from San Bergmans)

The electrical portion of the infrared remote control is very simple consisting of an infrared receiver, TSOP4838 from Vishay semiconductors, and a resistor and capacitor to improve the robustness of the circuit. The majority of the work done to incorporate an infrared remote control is accomplished in the microcontroller.

2.2.7 Motion Sensor

From the most sophisticated laser beams to the simplest infrared detector, the sole purpose of motion detection systems is to detect some "body". The sensing of motion can be something at a very specific location (local) or in a larger area. Local motion detection can be accomplished through active infrared (light beams), contact or tilt switches, proximity sensors or strain/stress sensors, while area detection is accomplished through passive infrared, proximity sensing, microwave/radar, ultrasonic wave detection, vibration or video. For our project we required some form of area detection around the fountain. With this in mind we researched ultrasonic, microwave, video and passive infrared detection technologies for our motion detection method.

2.2.7.1 Video

Video motion detection uses a closed circuit television system. The monitoring system constantly scans the images from the cameras for changes in the ambient light to detect motion. These types of systems were too expensive and overly complicated for the needs of this project. The idea of using video to detect motion was quickly discarded as a viable means of detection.

2.2.7.2 Ultrasonic

Ultrasonic motion detectors generate ultrasonic waves and recognize disruptions in the waves to detect motion. When someone enters the area of detection waves are reflected resulting in a change in the wave pattern and signaling motion in the area. While ultrasonic sensors are relatively inexpensive they are prone to false motion detection signals caused by excess air currents that disturb the wave pattern. Our application requires an outdoor installation, so we felt that this type of sensor was not the best choice for our project.

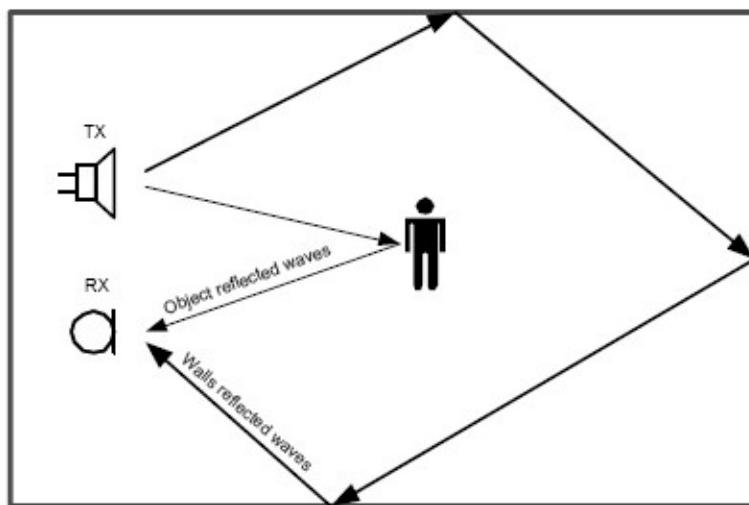


Figure 16: Ultrasonic motion detector (Image used with permission from the Cypress Semiconductor Corp)

2.2.7.3 Microwave

Microwave detectors use the same principles of detection as ultrasonic except that they use a much higher frequency wave. These higher frequency waves can penetrate all construction materials, i.e. brick, wood, concrete and drywall. With this added sensitivity, we felt that this sensor would also provide too many false motion detection signals.

2.2.7.4 Passive Infrared

Passive infrared detection circuits detect the infrared radiation given off by all objects. To detect motion, the sensing circuit will compare the infrared signal

from two sensors and, by using the differences in infrared radiation, detect motion. This type of sensor is shown in Figure 18 below.

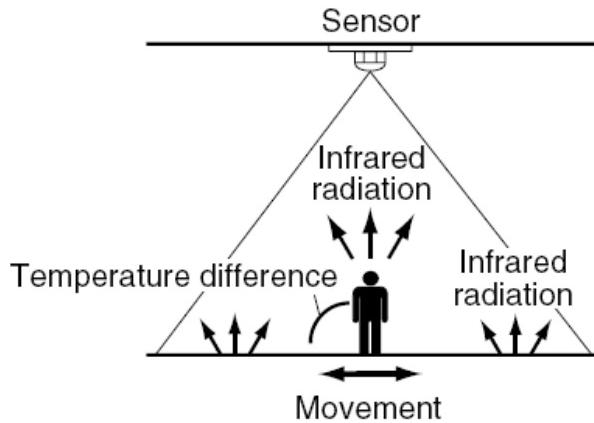


Figure 17: Passive Infrared (Image used with permission from the Panasonic Co.)

The passive infrared motion detection was the easiest and most cost effective method to implement for our project. Once this method was selected, we needed to research sensors and the supporting circuitry to interface them with the microcontroller. We wanted to be able to detect motion from at least ten feet away and with a horizontal field of coverage at least ninety degrees.

We came across several sensors from different manufacturers. To maximize the effectiveness of the motion sensor, we needed as wide a field of coverage as possible in both the horizontal and vertical axis as well as long range and slow movement sensitivities. We utilized Google, Newark and Digi-key's websites to narrow down the selection based on our voltage and range requirements. We found sensors from Panasonic Electric Works, Murata Manufacturing Co. and Nicera Philippines Inc. that met our basic requirements.

The selection was further narrowed down by price; the sensor from Panasonic Electric Works was immediately eliminated because it cost over one thousand times as much as the sensors from Murata Manufacturing and Nicera Philippines. Next we compared the horizontal and vertical detection angles of the remaining sensors. The sensors from Murata have a viewing angle of 45° left and right of center. The sensor from Nicera has a viewing angle of 62.5° left and right of center; the Nicera sensor has the advantage over the Murata sensor. Finally, we looked at the cost of the sensors and their respective Fresnel lenses. The Nicera sensor and lens were both cheaper than the Murata sensor and lens. Knowing all of the factors, we chose to use the Nicera Philippines RE200B pyroelectric passive infrared sensor coupled with a Fresnel lens for our motion detection circuitry.

A Fresnel lens is plano-convex lens, meaning one side is flat and the other is convex, which has been flattened while retaining its optical characteristics. This is shown in Figure 19 below.

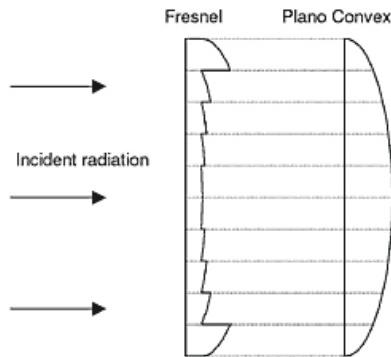


Figure 18: Fresnel vs. Plano Convex Lens (pending permission from Questex Media Group)

The lens is now thinner and has had its absorption losses reduced. The flat white window seen on motion detectors is the flat side of the Fresnel lens. The lens condenses the incoming light allowing for a longer detection length. So that there are not just two large rectangle sensing areas, the lens is comprised of multiple sections. Each of these sections is a Fresnel lens which creates multiple smaller detection areas. With different facetting and sub-lenses the overall lens creates a range of detection areas that are interleaved with one another. These detection areas are then focused onto the sensor as seen in Figure 19 below.

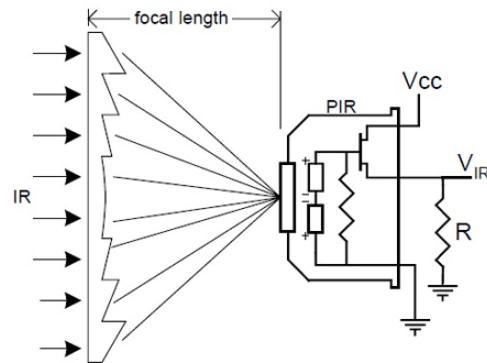


Figure 19: PIR Sensor with Fresnel Lens (Image used with the permission of the Cypress Semiconductor Corp.)

These focused beams allow the sensor to have larger coverage areas and greater depth of coverage within these areas. Using the Fresnel lens in conjunction with the passive infrared motion sensor greatly enhances the

functionality of our overall design and allows us to conserve energy and resources when the fountain is not being viewed by anyone.

2.2.8 Ambient Light Sensor

During the daylight hours the light from the LEDs is not very visible. In order to conserve energy, the LED drivers are turned off during this time. In order to accomplish this task we implemented a day/night sensor circuit to provide input to the microcontroller. There are two photosensitive components we looked at to use in our day/night circuit, the light dependent resistor and the phototransistor. Light dependent resistors, or photoresistors are resistors that decrease their resistance with increasing light intensity. Light dependent resistors, or LDRs, are made of highly resistive semiconductor materials. As the light intensity increases on the LDR, bounded electrons absorb enough energy to jump to the conduction band. This addition of these free electrons in the conduction band causes the overall resistance of the LDR to decrease. LDRs based on cadmium sulfide (CdS) have a sensitivity curve that closely resembles the sensitivity response of the human eye. LDRs have a range of resistance from less than $100\ \Omega$ when fully illuminated to greater than $10\ M\Omega$ in darkness. LDRs can be found in various applications such as clock radios, security alarms, and street lights.

There are several factors that limit the applications of LDRs. The resistance of the sensor is dependent on the thick film microstructure of the semiconductor material. This allows for a wide tolerance in the sensor's resistance. The resistance also has a long term memory which is governed by the amount of light the sensor is exposed to and the light history of the past several days.

Phototransistors are transistors designed in a transparent package that allow the light to bias the transistor. The base current of the transistor is generated by light striking the base collector junction of the transistor. As base current is generated, we see a marked increase in the collector current. This built in gain allows the device to accommodate TTL level voltages for a wide range of light levels. Phototransistors are sensitive to light wavelengths from 300 nm to 1100 nm; this spectrum range fully encompasses the visible spectrum of the human eye. Phototransistors also have a quicker response time than that of the light dependent resistor.

Since the cost of a phototransistor and a light dependent resistor are comparable to one another and the better overall response is received from the phototransistor, we chose to use the phototransistor for the basis of our ambient light sensor circuitry.

To select the phototransistor necessary for our design, we set up a few basic requirements such as wavelength sensitivity, dark current, viewing angle, mounting style, and cost. For the wavelength rating, we wanted a transistor that was sensitive to the same wavelengths that are visible to the human eye. Since the human eye can typically see wavelengths from 380 to 750 nm, we wanted a phototransistor with wavelength sensitivity centered about a wavelength of 565

nm. Phototransistors are commonly made from silicon, germanium, indium gallium arsenide, and lead(II) sulfide. Phototransistors made from silicon have wavelength sensitivities from 190 to 1100 nm and germanium phototransistors have sensitivities that range from 400 to 1700 nm. Phototransistors made from indium gallium arsenide (InGaAs) or lead(II) sulfide (PbS) have wavelengths that fall outside of the useful range of our project. The range of spectral sensitivity from silicon phototransistors covers the range of wavelengths we desired so we concentrated our research on silicon based phototransistors.

We wanted to keep the dark current rating as low as possible. The dark current is extremely temperature dependent and limits the minimum static light level that can be reliably detected; the lower the dark current rating, the greater the accuracy of our detector. As for viewing angle, the wider the better; however since we are only looking to detect ambient light and not the light of a very specific area, this requirement carried less importance. Using these criteria we narrowed our choice down to Vishay Semiconductor's TEPT4400. This phototransistor met all of our criteria and it is a low-cost device as well.

2.2.9 Nozzle Flow Cutter Mechanism

The cutting mechanism portion of the flow nozzle is used to redirect or block the laminar stream of water leaving the flow nozzle. Several factors were taken into account before we could settle on any one particular design. The factors involved are the overall size of the mechanism, speed as it moves to block the water stream, voltage and power requirements of the actuator, the control circuitry to activate the mechanism, its ability to withstand the environmental factors it will be subjected to, and cost.

Overall size of the mechanism was important because it is mounted directly on top of the flow nozzle. Since we've decided to go with smaller nozzles in order to reduce the size and cost of the water pump, we have reduced the available mounting surface area available for the cutting mechanism. The next factor we considered is speed, if the cutting mechanism is too slow it will cause turbulence in the stream's leading or trailing edges, causing the stream to break apart. While this does not affect the nozzles operation, it diminishes the aesthetic effect of the fountain as a whole. As we are utilizing a single voltage power source in our design, the actuator must operate using 5 VDC or less. Each of the different actuating methods we looked at required a different type of control circuitry. These control circuits range from a bipolar stepper motor driver to a simple DC circuit to actuate a linear solenoid. Once again the voltage requirement of the control scheme selected is limited to 5 VDC. Cost is the final factor which must be addressed. As a group we are solely funding this project, therefore we have agreed to use the most economical methods and parts when designing this project.

After taking each of these factors into account we had the following methods of actuation as viable solutions: linear solenoids, stepper motors, servo motors and rotary solenoids.

2.2.9.1 Linear Solenoids

Linear solenoids are readily available, come in a wide variety of specifications, and are relatively easy to interface with a microcontroller. We had two main types of linear solenoids to choose from, push or pull. In the design, we considered a linear solenoid which, when energized, would push a blade/arm into the stream of water to block it. It would then spring return to the unblocked position when de-energized. This configuration would have left the solenoid de-energized most of the time thus preventing the coil from overheating and extending its useful lifetime.

Next, we took into account the solenoid's ability to function in an outdoor environment. While measures will be taken to minimize the occurrence, it is inevitable that at some point the solenoid will get wet. To this end, if an open frame solenoid were implemented it would require added environmental protection through some kind of housing or shielding. To eliminate this requirement, we focused our research on tubular solenoids which completely house the coil of the solenoid. This eliminated the need of additional housing or shielding thereby reducing cost and the overall footprint of the cutting mechanism. Unfortunately, we were unable to find a suitable solenoid that would operate on a 5 volt supply.

2.2.9.2 Stepper Motor

The next possible solution was to use a stepper motor. Stepper motors can be precisely positioned without the need of feedback. This would have allowed us to move the cutting arm into and out of the water stream with a high degree of accuracy. There are three main types of stepper motors: permanent magnet, hybrid synchronous and variable reluctance. Most of the hobby stepper motors we researched were permanent magnet stepper motors. These stepper motors were generally two phase stepper motors, meaning they either had unipolar or bipolar winding arrangements for the electromagnetic coils. Each of these configurations has its advantages and disadvantages.

The unipolar stepper motor has the advantage of a simpler control circuit as you do not have to switch the direction of current through the windings in order to reverse the pole of the electromagnet. There are two windings per phase, one for each direction of the magnetic field. This would have relieved us of the need to switch the direction of the current through each of the windings. The drawback to this scheme is that only 50% of the windings are utilized, therefore the performance is low to moderate, but it also generates less heat. The lower performance of the unipolar motor was not a concern for this application because we would only be moving the motor to two locations and even that would only be on an infrequent basis.

The bipolar stepper motor has the advantage of utilizing 100% of the windings and therefore provides more holding torque. This advantage is not necessary for our purposes. With only one winding per phase, the current through the phase must switch direction in order to reverse the magnetic poles. To accomplish this

switching, a more complicated driver would have been required, most likely an H-Bridge arrangement as shown in Figure 20 below.

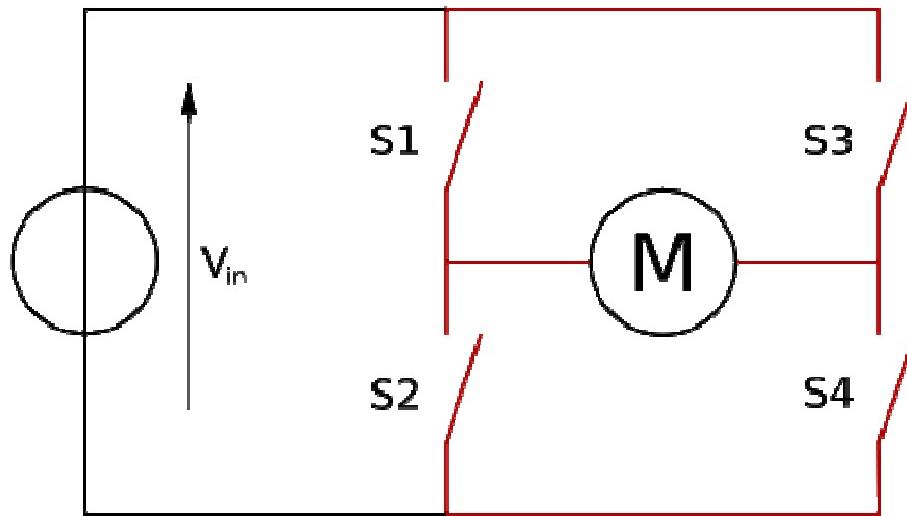


Figure 20: Bipolar Stepper Motor (Image used with the permission of Cyril Buttay)

The use of a stepper motor would have also required it to be shielded or sealed against the environmental conditions. While sealed stepper motors can be found, the added cost must be factored into the selection process. Both the unipolar and bipolar stepper motors can be run using the 5 VDC power supply and they are relatively small so speed of actuation would not be a problem. Looking to minimize cost and to keep the driver design as simple as possible we ruled out using a bipolar stepper motor because of the more complicated controller circuitry.

2.2.9.3 Rotary Solenoid

The next actuation option was the rotary solenoid. Rotary solenoids also come in a wide variety of specification and they, too, are easily interfaced with a microcontroller. With rotary solenoids, instead of push and pull actions, they have clockwise and counterclockwise rotational action. Either of these actions would have suited our purpose. When energized, the solenoid would rotate the cutting arm into the laminar stream, blocking the flow of water. When we no longer wanted to block the stream, the solenoid would be de-energized and spring returned to the home position. This scheme of actuation minimizes the period when the coil of the solenoid is energized and thereby minimize coil heating and extend the lifetime of the coil. Unfortunately, like the linear solenoid, we were unable to locate a suitable solenoid that would actuate with such a low supply voltage.

2.2.9.4 Servo Motors

The final actuating method that was available to us was the servo motor. Servo motors are motors that are mechanically linked to a potentiometer; the internal electronics convert a pulse width modulated signal into a position command. Once the signal is received by the internal electronics, the motor is energized until the potentiometer reaches the desired value corresponding to the signaled position. The desired position is determined through the width of the pulse received by the servo. A pulse width modulated signal can easily be developed using the pulse width timer in a microcontroller or through a simple driver circuit using a basic timer microchip like the LM555.

The servo motor also allows us to accurately position the cutting arm without the need for feedback circuitry. The servo motors are generally small in size, high speed servos are readily available, most servo motors run on a 5 VDC supply voltage, and the control circuitry is designed with or without using one of the pulse width modulated outputs from the microcontroller. Basic servo motors used in radio controlled hobby designs are inherently designed to withstand the environmental factors that our project subjects them to. The only prohibitive factor against the use of the servo motors was the cost as compared to some of the other actuator choices.

Based on our research it appeared that, in order to maintain a single voltage power supply scheme and to keep costs down, the use of servo motors was our best option. After all of our research was completed, we selected a HITEC HS-56HB servo. This servo has a 0.12 second/60° speed rating and 13.88 oz-inch torque specifications. The servo has the following dimensions (units are in mm):

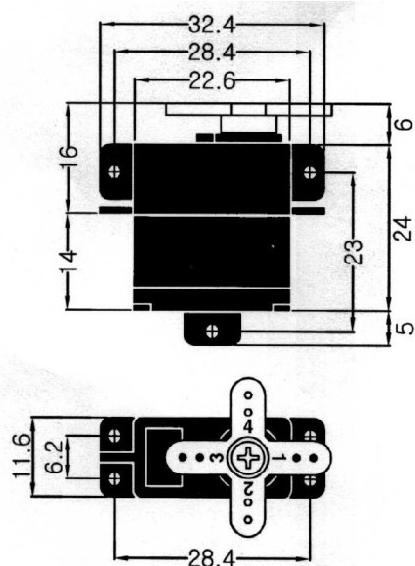


Figure 21: HITEC HS-56HB Servo Dimensional Drawing (Image used with the permission of the HITEC RCD USA)

2.1.9 Fiber optic to LED interface

In order to transfer the light from the LED's to the laminar flow cutter, we are using the LED/Fiber coupler shown below.

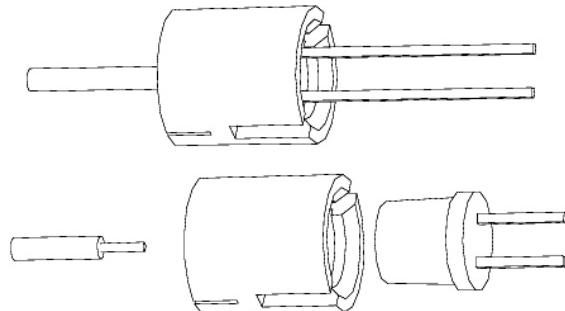


Figure 22: LED to Fiber Coupler (pending permission from Fiber Optic Systems Inc)

The coupler sits over the LED and creates an interface between the LED and fiber cabling. Through this coupler, the light from the LED travels down the fiber cabling to the laminar flow cutter. At that point the light is transferred to the water.

2.2.10 User interface

The user interface allows the user some basic controls over the fountain system for both aesthetic and troubleshooting purposes. We are integrating basic ON/OFF controls for each of the primary colors of the LEDs, the ability to de-energize the entire system, the ability to power up and down the water pump, and the ability to control the cutting mechanism of each nozzle. To accomplish most these basic tasks, the microcontroller is only required to receive 1s and 0s, i.e. 5 or 0 VDC, at the appropriate digital I/O point to carry out the desired action. For the system and pump power control we are incorporating basic toggle or rocker switches, with sufficient voltage and current ratings, to control the AC power to each of them respectively. As for controlling the LEDs and the cutting mechanisms, the main design limitation was to ensure that it was an intuitive design for ease of user operability and functionality. There is one other main factor we took into consideration beyond the electrical specifications, and that was cost. We researched several possible solutions from simple toggle switches to graphical LCD touch panels.

2.2.10.1 LCD Touch Screens

Liquid crystal display (LCD) screens come in almost any shape or size. They can be custom made to suit most needs. Used in conjunction with touch pad overlays, they can create a touch panel. The LCD screens are segregated into two main categories, alphanumeric which only display alphanumeric characters, and graphic displays which can display bitmaps and alphanumeric characters. A graphic LCD (GLCD) touch panel with a bitmap could have been used to supply the user interface. We briefly looked into using a GLCD touch panel but we

quickly determined that the material cost, added programming, and the amount of I/O required to implement this configuration was not cost effective or necessary as it would have only been a secondary user interface in the event that the infrared remote control was no longer working.

2.2.10.2 Manual Switches

In lieu of using the GLCD touch panel, the next logical choice for the user interface was simple electromechanical switches. The switches we needed for our project were one of the very last items we researched. There is more to switch selection than just ON and OFF. There are four basic steps we used to select the appropriate switch. They were user needs, engineering limitations, actuator type, and ensuring that the switch is robust enough to withstand the environment in which it is operated in. Following these basic steps ensured that our switch selection satisfies all the needs of our project. The first step was to see how the user interacts with the interface. A poorly designed interface can prevent a great idea from ever being utilized because it is too difficult for the user to use or understand. We looked at what size would be appropriate and how often it would be used. For instance the system and pump ON/OFF switches are going to be used more often than the backup switches used to control the lighting sequences, and therefore they are larger, easily accessible, and clearly labeled.

After determining the user needs, we next considered the engineering limitations of each switch. Knowing the load requirements is essential for proper switch selection. Is the load inductive or resistive? What voltage and currents are being passed through the switch? Contact materials and power ratings are important. What kind of mounting is necessary? How much space is available? What types of terminations are required and or desired? All of these questions placed some type of engineering limitation that we considered before selecting switches.

The third step was determining actuator type. There are a wide array of options to fit any and all design needs. There are pushbuttons, toggles, rockers, sliders, rotary, momentary or maintained, illuminated or non-illuminated and they all come in various colors and sizes. Each style has its own unique use and, if chosen correctly, can serve to enhance the user interface.

The final step was ensuring that the switch withstands its environment. Our switches are located in a suitable enclosure for outdoor use. Since we live in Florida, the switches see temperatures in excess of one hundred degrees and high humidity as well. We needed to ensure that each switch met the appropriate IP code rating. For example IP 65-rated switches protect against dust and direct high-pressure sprays of water, and IP 67-rated switches protect against temporary immersion in up to 1 m of water. At the other end of the spectrum, IP 60-rated switches only protect against the ingress of larger, solid objects such as dirt.

The most electrical rating sensitive switches are the system and pump power switches. The water pump for our project has ratings specified by the

manufacturer. The project utilizes a 110 VAC, 60 Hz, single phase, 0.5 hp, 0.37 KW centrifugal pump. This means that it has a running current of approximately 3.4 amps. Since the motor on the pump is an inductive load we were concerned about the in rush current; in rush current being the initial instantaneous maximum starting current of a device. An AC electric motor can draw several times its full load current when it is first energized. If the switch were undersized for this current, the contacts would be fused together. To keep this from happening, we selected switches based on not only the running current and rated voltage but the power requirement of the pump as well. To this end we selected a non-illuminated rocker switch, part number YRM22S2DBRNN, from the Cherry Corporation that was rated for 125 VAC, 20A, $\frac{3}{4}$ HP. This switch is slightly oversized for our needs but we were unable to find a suitable switch at exactly $\frac{1}{2}$ hp rating. Since it is always safer to oversize the ratings of a switch than undersize them, we felt this was a satisfactory solution.

The next switch we looked at was the AC power to the 5 VDC power supply switch. Since all of the loads on 5 VDC power supply can be treated as resistive loads sizing of this switch was much less complicated. We used the maximum output voltage and the maximum current output from the linear voltage regulator in the power supply of $5V \pm 3\%$ and 3A to appropriately size this switch. Using these ratings we selected the C&K Components 125 VAC 4A non-illuminated rocker switch part number D102J12S217DQA from Digi-Key Corp. Knowing the ratings for this switch and the pump power switch, we know that we can also use the same switch from the pump to control the AC power to the entire system. This switch allows us to turn off all systems at one time.

For the manual control of the individual nozzle cutter mechanisms, we felt that a momentary pushbutton was the best actuator type. Since we did not want the water streams continuously blocked but pulsed to give the appearance of the water “jumping,” this style offered the most intuitive solution. Using the criteria of a momentary pushbutton with a normally open contact was the basis for our search. For aesthetic reasons and for clarity we chose a round pushbutton to help differentiate the nozzle switches from the system and pump power switches. The normally open contact inputs a logical 0 to the microcontroller during normal operations and when the nozzle cutter is to be closed the pushbutton is depressed and a logical 1 is sent to the microcontroller to actuate the cutter servo motor. When the button is released the cutter will travel back to the unblocked position.

The final switches we needed were the switches to provide digital inputs to the microcontroller for user selections. While these switches are a backup method of control, we still needed to follow the four basic steps of switch selection. These switches allow the user to manually select the preprogrammed lighting sequences or to manually control which LEDs are continuously on or off in lieu of the infrared remote control. Due to the large number of digital inputs required to provide this functionality, the switches needed to be relatively small but still easy to operate. The electrical ratings for the switches were not hard to meet since

they are only passing 5 VDC and virtually no current. The actuator style we decided that would provide the necessary functionality for the user and would easily satisfy the electrical rating requirements is the dual-inline package or DIP switch. This type of actuator also alleviates the need to allocate a relatively large space to accommodate so many switches. Again, like the other switches utilized, the DIP switches are mounted inside the enclosure; this precludes the need to make them weather resistant as they are fully protected from the elements.

2.2.11 Pump Controls

To control the pump we have installed a relay into the voltage supply line for the pump. Our original goal was to try and accomplish this without using a float switch. This lead us to research a circuit that had 2 exposed metal probes set at different depths. When the water was at an adequate level the circuit was complete, causing a closed path for current. We found a schematic on instructable.com that achieved this circuit with 3 volts, one NPN transistor, 2 resistors and a potentiometer. When the water fell below the acceptable level, the LED went out indicating to the user that it was time for a water refill. Due to the changing conductivity of tap water, the potentiometer could be adjusted for proper circuit operation.

However, there were a few problems with this circuit. While it indicated to the user that the water was at an acceptable level, it didn't turn off the pump when the LED extinguishes. Modification of this circuit could have been considered, but after discussion, it was decided that placing exposed metal rods into water and then applying voltage would probably not be the best idea. If our fountain was fully enclosed and not exposed to human interference, this idea may have been worth further exploration.

Next, we decided that a float switch would most likely be the most efficient method of pump control. Float switches come in 2 designs, normally open and normally closed, and many float switches can be modified to run in either mode. For our purposes we needed a float switch that is normally closed and only opens when water levels fall below the determined safe zone. We accomplished this by attaching the float switch to the side of the fountain basin; when the float switch changes states, the power to the pump is deactivated. We looked for a float switch that operates at 5V; this float switch is in series with a 5V relay that controls the pump. It would have been possible to just place the float switch in series with the pump and not use a relay, but when pumps start they can draw up to 10 times their steady state current. This can lead to quick destruction of a float switch. So, in order to avoid this condition, we placed the float switch on a circuit that is isolated from the pump. This isolation will extend the life of the float switch. Float switches come in many variations and many materials. For our purposes, we needed as inexpensive a float switch as possible. Looking at aquarium enthusiast websites gave use more economical options then the plumbing sites.

In researching the circuit, we found a design for a relay circuit on http://lava.lounge111.net/diy_water_level_alarm.htm. This circuit, with some

slight modifications, was ideal for our applications. The following circuit is the unmodified circuit from the lava lounge site:

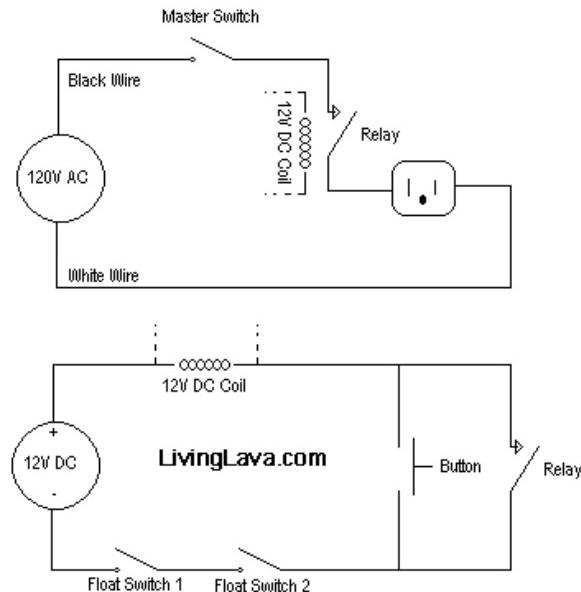


Figure 23: Living Lava Low Water Level Alarm (pending permission from Living Lava)

We modified the circuit to contain a 5 volt relay instead of 12V. This allowed us to use the same voltage for all circuitry on the PCB. Our circuit also does not contain the push button shown in the lower portion of the schematic.

We decided to use the i-float switch from Aquahub (FLT001). This float switch is normally closed, but can be changed to normally open. The max switching voltage is 220VAC and max switching current is 2.5A. These specifications are more than sufficient for placement into our 5V line. According to the manufacturer's specification sheet: "When the float drops to within .12" (+/- .04") of the bottom clip, the internal reed contacts draw together and complete a circuit. When the float rises .20" (+/- .04") from the bottom clip, the contacts separate and open the circuit." Because this is the normal operation of the float switch, we changed the operation by taking off the float and inverting it. This allows the float switch to operate in the manner we need to complete our circuit. We also eliminated one of the float switches shown above. The above design uses two float switches to monitor the water level between 2 distinct water levels. Since we are only concerned with the low level consequences, we are not monitoring a high level situation.

The relay we are using must handle normal household power on the secondary circuit. A single pole single throw circuit (SPST) is sufficient in this design. In conducting research we found that there were many SPST relays to choose from, but when we started narrowing our parameters to include only those relays that function normally closed, our options dwindled fast. The relay we found was

from Omron and is the G6B-2114P-US5. It is a SPST normally closed relay that supports up to 5 amps on the secondary coil. This is important because the pump is rated for 3.4 amps. This relay is a through-hole board mount part.

2.2.12 Printed Circuit Board

As part of our project we designed a PCB that will house all of our circuitry. We needed a PCB of sufficient size to contain the following circuitry:

- LED drivers
- Microcontroller circuitry
- Peripheral interface
- Pump controls
- DSP circuitry
- 5V Power Supply
- Color Organ

Because of our limited knowledge of PCB fabrication, we needed first to research what exactly is involved in fabrication and the terminology used to discuss this topic. Xilinx has a PCB designer's guide for the Virtex-5 FPGA, although we are not using the Virtex-5 FPGA, the information in the introductory chapter covers PCB design basics. The designer's guide states "PCB technology has not changed significantly in the last few decades. An insulator substrate material (usually FR4, an epoxy/glass composite) with copper plating on both sides has portions of copper etched away to form conductive paths. Layers of plated and etched substrates are glued together in a stack with additional insulator substrates between the etched substrates. Holes are drilled through the stack. Conductive plating is applied to these holes, selectively forming conductive connections between the etched copper of different layers."

We determined the number of layers needed for our design. The number of layers is determined by number of signals, and how many power and ground planes are used. We attempted to keep the most simplistic approach to our fabrication in order to keep our costs down. As the number of layers increase, the cost of the PCB also increases. We have a 5V power plane and a ground plane. If we adhered to the Virtex-5 guidelines we would have been looking at a minimum of 4 layers. One layer would be for ground, one layer would be for 5V power, and the third layer would contain our signal layer. Normally the signal layer is sandwiched between the power and ground layer in order to isolate the signals from external noise.

While researching the PCB development process, we realized that on our constrained budget it would be difficult to economically design a multilayer board. We researched the following options for possible PCB fabrication firms: PCB123, 4PCB and ExpressPCB, as well as a Do-It-Yourself method.

PCB123 allows the user to download their software for free, design a board and have it fabricated within a short amount of time. The pricing structure is straight

forward and listed on the website in an open manner. The website states that a single sided PCB can be turned in one day, for an order smaller than 75 PCBs. PCB123 allows designers to design boards up to 6 layers. This allows for increased complexity of our board design, but, as the number of layers increases, so does the price. One aspect of PCB123 that is appealing is their large parts library. When designing a board, it is important to have the proper footprint for the part you are installing. By working with software that includes a large number of parts, the chance of us using the incorrect footprint significantly decreases. The software also does real time parts pricing from DigiKey. This aspect is appealing because it allows us to create our PCB and simultaneously create a parts list for ordering the needed parts. PCB123 also offers a discount to unsponsored senior design groups of \$100. This discount is appealing in light of the fact that our sponsorship for this project fell through.

The second company we looked at for PCB fabrication was ExpressPCB. This company offers all its own software for free download, which is similar to PCB123. They recommend using their software to create a schematic first, then linking the schematic to the PCB to make the design process easier. They offer an array of different types of boards from single to double sided and varying sizes as well. They do not however offer 6 layer boards, but given our lack of actual PCB design knowledge, we know that we aren't designing a board of that magnitude. ExpressPCB offers what they call a Standard MiniBoard for a fixed price of \$51.00 this would include 3 identical PCBs that are 2 layers and 3.8X2.5in. However, if we were to have varied from this standard size the pricing structure becomes less straight forward.

The formula they use for the standard 2 layer board is:

*The cost of your PCB order depends on the size and quantity of the boards. Our pricing formula is: $\$55 + (\$0.65 * \text{NumberOfBoards} * \text{BoardAreaInSquareInches}) + (\$1.00 * \text{NumberOfBoards})$.*

That means that two 3x5 boards cost \$77, whereas one 3x5 two layer boards from PCB123 cost \$48.50.

The last company we looked at was 4PCB. 4PCB offers the same benefits as the previous 2 companies with lower prices. They have downloadable software for schematic and PCB design, but at a substantially lower cost. For Senior Design students they offer a \$33.00 two layer PCB. This PCB can be any size up to 60sq inches. And they also offer a four layer board for only \$66.00. The only drawback to using this company is the 2 week lead time on all purchases, but with proper time management this should not be a make or break issue.

We also looked in to a Do-It-Yourself PCB method; we could have used a press-and-peel PCB transfer system. This process would have allowed us to manufacture a PCB in our homes. Once the PCB design is laid out using a PCB design program, it would be printed to special press-and-peel paper using a laser jet printer. The press-and-peel paper is a Mylar backed paper that inhibits the ink

from absorbing into the paper and drying after printing. The laser jet printer ink would then be transferred to a clean copper clad PCB board using a heated iron. It is very important to be sure the copper clad PCB is clean. Once the PCB is fully cooled the press-and-peel paper is pulled away leaving an imprint of the routing on the PCB. The PCB is then soaked in a muriatic acid solution to remove the exposed copper. Then the board is cleaned, drilled, and prepared for component mounting. Although this method appears to have quite a low cost, the incurred cost would be in dealing with chemical and adhering to the proper hazmat disposal methods for the spent acid which would contain copper (a heavy metal). We would have also been responsible for the drilling of the through holes; lacking the proper equipment to make these holes would result in greater cost for purchasing the appropriate equipment. Oxidation also occurs quickly, and we would have had to purchase a sealant in order to protect the copper runs.

After careful consideration, it was decided it would best benefit us to have a manufacturing company spin our PCB. Our largest constraint in this project was price. Comparing the manufacturing companies led us to choose the most economical option; 4PCB was our choice for our PCB fabrication needs. At the point of our research, we were unsure of the dimensions of our PCB. 4PCB allowed us the flexibility to change the sizing of our board without changing the price we will be paying for the board as long as we stay within the 60sq. inches specified by 4 PCB.

2.2.13 Enclosure

The enclosure is responsible for housing the Printed Circuit Board Assembly. This assembly will be slightly larger than 60 square inches so that it can house our PCB and other circuitry. Because we are certain of the maximum size of the PCB, we chose an enclosure that comfortably houses the PCB and the attaching hardware. Because of the risk of electrostatic damage to the PCB, the enclosure we chose is ESD safe. To conform to our pricing structure we did not spend more than \$15.00 on an enclosure.

2.2.14 Fiber Optic Transmission Lines

Fiber optic transmission lines are made of either plastic or glass. The light is transmitted down the fiber. A fiber optics cable usually consists of a core, cladding, coating, strengthening fibers and a cable jacket. Because our transmission lines are placed within the laminar nozzle, we chose the smallest diameter cabling possible to transmit the light. Will have 2 transmission lines, one for each LED/nozzle.

2.2.15 Laminar Flow Nozzle

Laminar flow of any fluid agrees roughly with our innate sense of "smooth;" it is non-turbulent flow, flow free of swirls, eddies, back currents, or other disturbances. A completely laminar flow has no flow normal to it, only along it. When the flow is laminar, the flows in the stream are parallel and for flow

between two parallel surfaces we consider the flow as made up of parallel laminar layers. In a pipe, these layers are cylindrical and may be called stream tubes. In laminar flow, no mixing occurs between adjacent layers and it occurs at low average velocities.

We chose to build our nozzle from basic supplies you could find in any home improvement store. The main body of our nozzle was constructed from four inch SCH 40 PVC pipe. SCH 40 PVC can easily withstand pressures in excess of two hundred pounds. This rating well exceeds the maximum discharge pressure of our pump. It is also relatively inexpensive as compared to any other potential building materials such as acrylic tubing or stainless steel piping. The nozzle also requires a means of reducing the velocity of the water entering. We considered several types of materials from foam filter pads for ponds to basic foam sponges. We chose basic foam sponges due to their low cost and availability. In order to straighten the water flow so that it is all traveling in the same direction and roughly the same speed we are using plastic straws.

As the water enters the large diameter of the nozzle body, it is moving at different speeds and direction, i.e. very turbulent. In Figure 24 below, we can see that the velocity of the water near the edges is travelling slower than the water in the center due to friction along the walls of the pipe. Having the water enter the straws forces the water to travel in a single direction and shapes the velocity profile of the water. As the water travels through the straws its velocity profile becomes more parabolic in nature. When all of the individual streams of water exit the straws they have similar velocity profiles. These streams then mix together creating a uniform velocity profile across the entire nozzle, essentially averaging the speeds of the individual straw flows. When the water reaches the exit of the nozzle it is all traveling at roughly the same speed and direction thus creating a laminar stream of water.

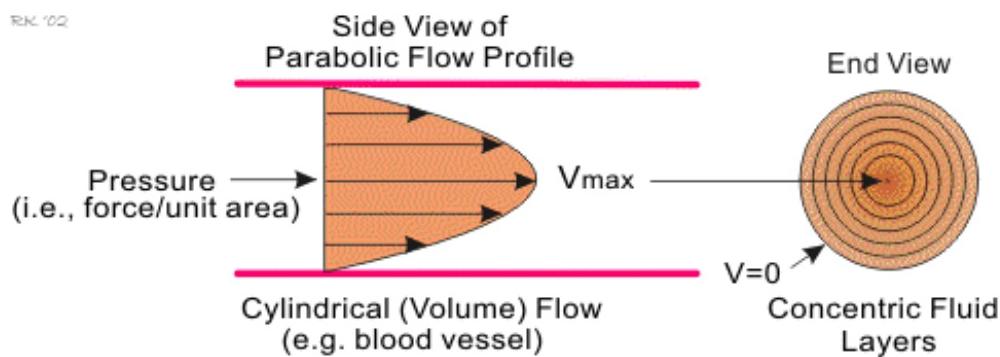


Figure 24: Velocity Profile of Laminar Fluid Flow (Image used with the permission of Dr. Richard E. Klabunde)

To ensure that the stream remains as laminar as possible as it exits the nozzle, we constructed the outlet of the nozzle as a smooth tapered hole. This minimizes the surface area that the stream is in contact with as it leaves the nozzle. With the surface area reduced, there is less friction on the outer edge of the stream which has a minimal effect on the velocity of the outside laminar layers of the stream. Creating a smooth taper with a sharp and well defined inner edge also prevents the stream from twisting as it travels out of the nozzle giving the stream the appearance of a smooth and clear glass rod as it travel along its arc.

2.2.16 Pump

One of the key components to the project is the water pump. There are five fundamental styles of pumps: direct lift, displacement, velocity, buoyancy and gravity. Direct lift consists of a volume of water lifted in a container, i.e. a rope and a bucket. A displacement pump moves a fluid by trapping a fixed volume and then forcing out the discharge of the pump, similar to a piston. A velocity pump increases the flow rate of the fluid to increase its kinetic energy. To increase the potential energy of the fluid, the velocity is slowed down just prior to entering the discharge of the pump. Buoyancy pumps or airlift pumps have compressed air injected into the lower end of a discharge pipe as the air rises. Due to its lower density than water; the water travels up the discharge pipe due to inertia. A gravity pump is simply a siphon. Out of these methods we quickly eliminated the direct lift and gravity methods. Next, we eliminated the buoyancy method due to its unstable flow rate and weak suction. This left us with the displacement and velocity pump methods.

Centrifugal and positive displacement pumps are the two most widely used pump configurations. Both have excellent lift and flow rate capabilities that could have satisfied or exceeded all of the needs of our project. Both can be run on single phase 120 VAC circuits. However, the displacement pump was eliminated due to two major factors; first is its tendency to have pulsation properties in its discharge. These pulsations make the stream out of the nozzle look like it is “bouncing” up and down. This subtracts from the aesthetic appearance of the fountain. The second and most important is cost. We were unable to locate a small positive displacement pump at a cost similar to a centrifugal pump. Even though the positive displacement pump had many excellent qualities, ultimately the centrifugal pump was chosen by default due to cost. Based on our research and project requirements we have selected a TEMCO centrifugal, single phase, 110 VAC, $\frac{1}{2}$ hp pump for our project.

2.3 Software

In order to program our microcontroller we had to make some decisions on which level of coding we wanted to use to create our software file. The PIC microcontrollers are able to be coded in either assembly or C. If we wanted to develop in C we would have had to use a C compiler compatible with the PIC family. Dr. Weeks was kind enough to point out that High-Tech C offers a C

compiler for the entire PIC family of microcontrollers. The software normally runs about \$500 for a standard license. But luckily for us, we are able to use the free version of the software. High-Tech C has an interface that easily allows us to assign the status of the I/O pins. This allows us to easily assign which pins would be set as inputs and which pins would be assigned as outputs. By selecting radio buttons of the I/O pins you wish to assign, the High-Tech program generates the C code needed for the I/O pins. The High-Tech C software also interfaces seamlessly with MPLAB.

MPLAB is the free software from Microchip, both Assembly and C programming languages can be used with MPLAB IDE. The MPLAB IDE contains tutorials and sample code to help with code development.

3 Design

3.1 Design Methods

After completing the research phase of our project we moved on to the design phase. In designing our Dynamic Liquid Light Fountain, cost was the largest objective. Next was size; we needed to design a product that could be easily transportable with a total cost under \$650.00. We also had to be sure that all components and circuitry for the PCB fit in an enclosure approximately 60 square inches in area. In adhering to these group imposed objectives, we set out to most efficiently design our fountain. The use of simulation software and laboratory breadboard process ensured that each circuit was functional before the PCB fabrication process began. This allowed for more efficient troubleshooting and testing processes.

3.2 Hardware

3.2.1 Power Supply

Thus far, we have looked into two different types of power supplies, linear and switched-mode. After reviewing the steps necessary to design both of the power supplies, we decided to build a standard linear power supply in order to power up the electronics for the Digital Liquid Light Fountain.

The main items we acquired/purchased for this power supply are a 120 volt AC step-down transformer, 4 power diodes (bridge-rectifier), 3 capacitors, a 5V/3A voltage regulator (LM350K), and 2 resistors - 1 240Ω resistor and 1 $5K\ \Omega$ potentiometer (to set the output voltage for the voltage regulator). After price-shopping all of the components, we kept the price around thirty dollars. We created a simulated power supply circuit verifying an output voltage of 5V in Multisim shown in Figure 25 below.

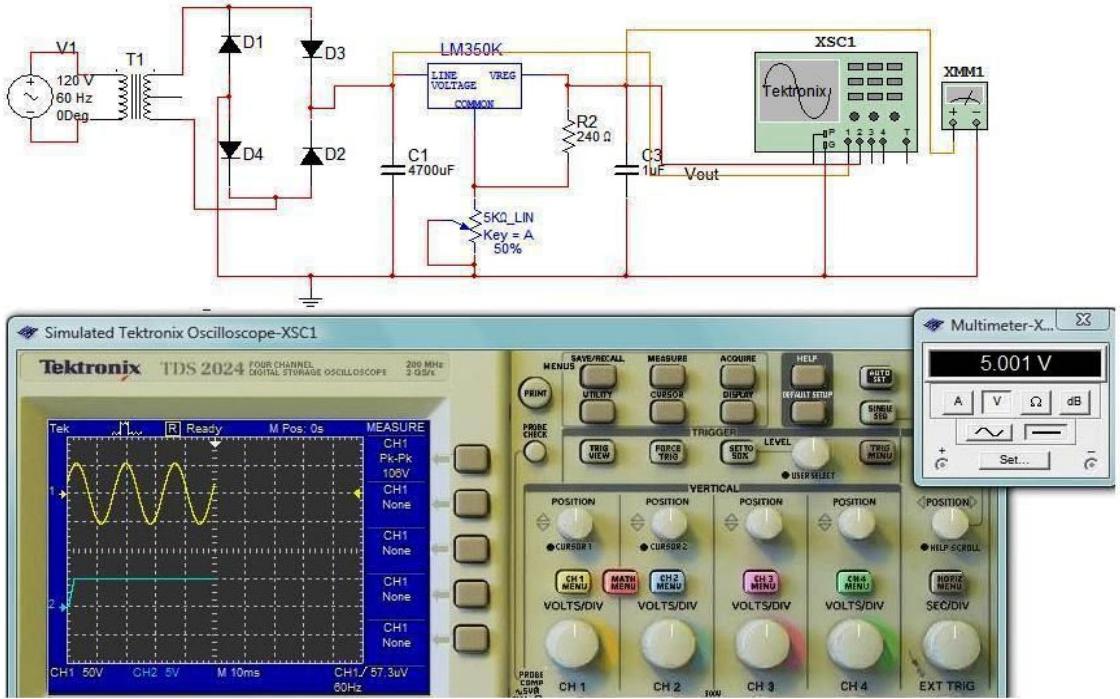


Figure 25: Simulated power supply circuit showing 120V AC input and a 5V DC output.

Depicted in the circuit is a 120 volt AC input voltage operating at 60Hz. We have a fused switch (not shown) located on the primary side of the transformer so that the user is able to shut off the 5V portion of the power supply while still maintaining 120VAC for the pump operation. This voltage is then transformed by a step-down transformer into approximately 12 volt AC using a standard 12 volt, 3 amp enclosed power transformer which we purchased from Radio Shack. Once the voltage is at a lower level, it is then rectified by a bridge rectifier which consists of 4 power diodes. From this point, the voltage ripples are smoothed out by a $4700\mu F$ smoothing capacitor. Finally, the LM350K voltage regulator ensures that we have a constant voltage level of 5 volts so that the elements in our circuit function properly. The output voltage is set at 5V by the voltage divider network consisting of a 240Ω resistor and a $5K\Omega$ potentiometer as per the voltage regulator specifications. The output current from the voltage regulator is guaranteed at three amps which will depend on the load applied to the supply. The input voltage (120VAC) is shown in yellow on channel 1 of the oscilloscope while the output voltage (5VDC) is shown in blue as a straight line. The digital multi-meter also confirms that the output voltage is measured at 5 volts as expected.

3.2.2 Microcontroller Interface

We are using the PIC16F887 microcontroller. The microcontroller does not require much by way of external circuitry for proper operation. We placed a bypass capacitor on the input power to further filter noise from our circuit.

There are 35 I/O pins on the PIC16F887. We are using 22 of the I/O lines as inputs. We are using 6 for the automated program selection, 2 for manual cutter control, 1 for water level, 1 for IR remote control, 1 for day/night sensor, 1 for motion sensor, 1 for initiating manual control of LEDs, 6 for LED manual on/off, 2 for external oscillator (for IR remote control), and 1 for color organ. We are also using 9 for outputs; they are 6 for LED control, 2 for cutter control and 1 for pump control.

Port A is being used for monitoring the inputs from the peripherals. Pin RA0 monitors the ambient light sensor. Pin RA1 monitors the infrared sensor. Those 2 inputs are then ANDed together and the resulting digital output determines if the environmental conditions are sufficient for executing code. Pin RA2 monitors the water level circuitry while pin RA3 monitors the IR remote control.

Port E monitors the inputs from the switches. Pin RE0 monitors switch 1, pin RE2 monitors switch 2, pin RE3 monitors switch 3, and pin RE4 monitors switch 4. If the remote control is in use the dip switches are all set to OFF. This indicates that the switch inputs are to be disregarded by the microcontroller. If the dip switches are set in the manual switch position, each switch indicates a program that has been selected. Only 1 switch is set to ON at a time, this allows for a total of four program to be selected. When all switches are set to 0, the Dynamic Liquid Fountain will dance to the music.

Port B contains the outputs to the LED drivers and the cutters. Pin RB0 is the output to signal to the green LED associated with the first LED driver unit. Pin RB1 is the output to signal to the red LED associated with the first LED driver unit. Pin RB2 outputs a signal to the blue LED associated with the first LED driver unit. Pin RB3 outputs a signal to the green LED associated with the second LED driver unit. Pin RB4 outputs a signal to the red LED associated with the second LED driver unit. Pin RB5 outputs a signal to the blue LED associated with the second LED driver unit. RC1 and RC2 control the cutter circuitry; this allows us to have at least 2 cutters and laminar flow nozzles. The laminar flow nozzle requires the use of pulse width modulation in order to open and close the cutter.

3.2.3 LED Drivers

Since one of the simplest and most inexpensive ways to provide power to a LED circuit and the way that is recommended by most is a constant current source, we looked at implementing this into our design for the DLLF. Typically, it consists of a small integrated circuit and several other outside components. The result is a constant current supplied to the LEDs no matter what type of input voltage exists or what type of forward voltage drop the LED has, which is especially important to consider when using high-power LEDs such as the ones we are using for the DLLF. Shown below in Figure 26 is a basic constant current source hooked up to a microcontroller, similar to the set-up we considered for the DLLF. This circuit shows multiple LEDs which is an option if we want to eventually increase the

amount of light provided to the water as it flows from the pump, but we are implementing a higher power LED instead. After reviewing the options available to us, we decided to go with a simpler circuit shown in Figure 26 below.

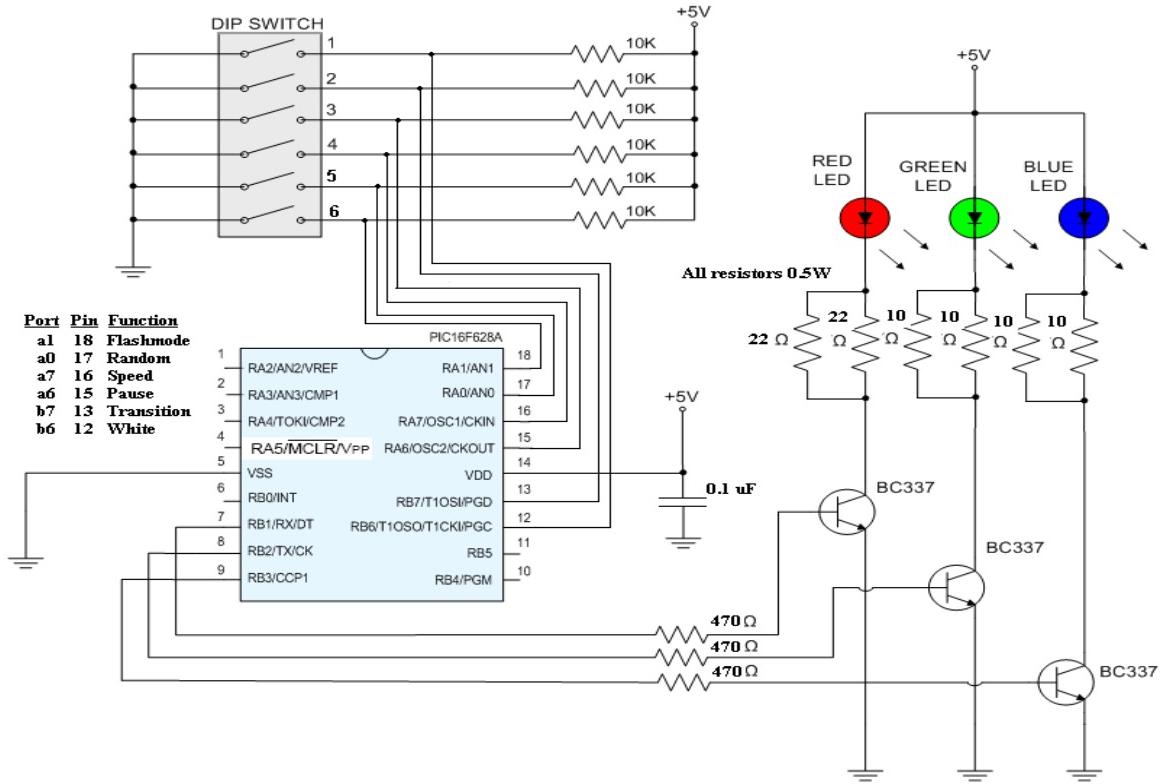


Figure 26: LED driver circuit implemented with microcontroller.

3.2.4 IR Remote Control Circuitry

The circuitry to support the infrared remote control receiver is relatively simple as seen in Figure 27 below. Resistor R1 and capacitor C2 are recommended by the manufacturer to improve the robustness against electrical overstress. X1 is the external crystal oscillator used to ensure the timing of the IR signal decoding loop. An external oscillator is used instead of an interrupt timer because the loop must run very fast, i.e. 50 microseconds. An interrupt timer would be too long due to the call, the return, and the necessary context switching that is involved. Capacitors C2 and C3 develop the load capacitance (C_L) for the oscillator crystal as specified by the manufacturer. Using the following equation and a value of 18 pF for C_L and 5 pF for the stray capacitance (C_S) we determined the value for C₂ and C₃.

$$C_L = \left[\frac{C_2 * C_3}{C_2 + C_3} \right] + C_S$$

$$18 \text{ pF} = \left[\frac{x^2}{2x} \right] + 5 \text{ pF}$$

$$x = C_2 = C_3 = 26 \text{ pF}$$

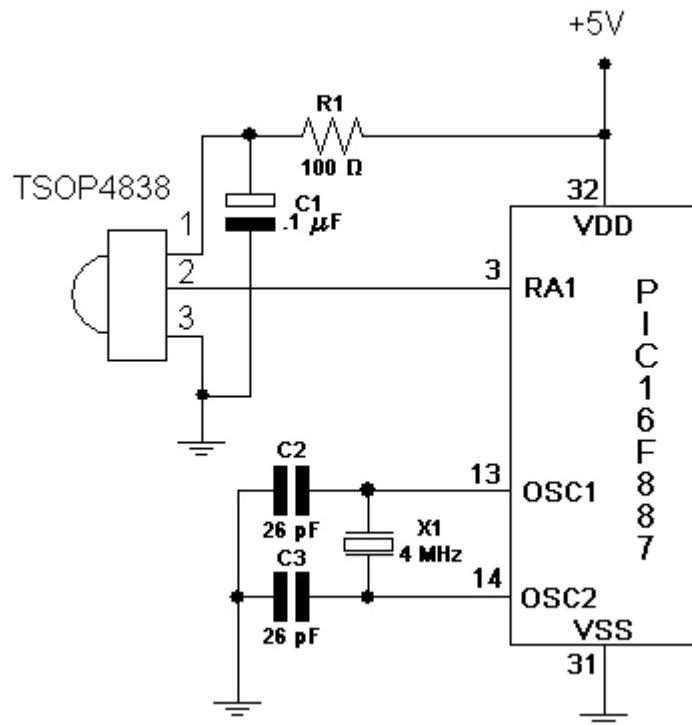


Figure 27: Infrared Remote Control Receiver Circuitry

The backbone to the implementation of the infrared receiver is software driven. The applicable code will be discussed in the software section of this document.

3.2.5 Passive IR Sensor Circuitry

The design of the circuitry for our passive infrared motion sensor is based on the circuit provided as an application example in the datasheet for the BISS0001 motion sensor decoder pictured in Figure 28.

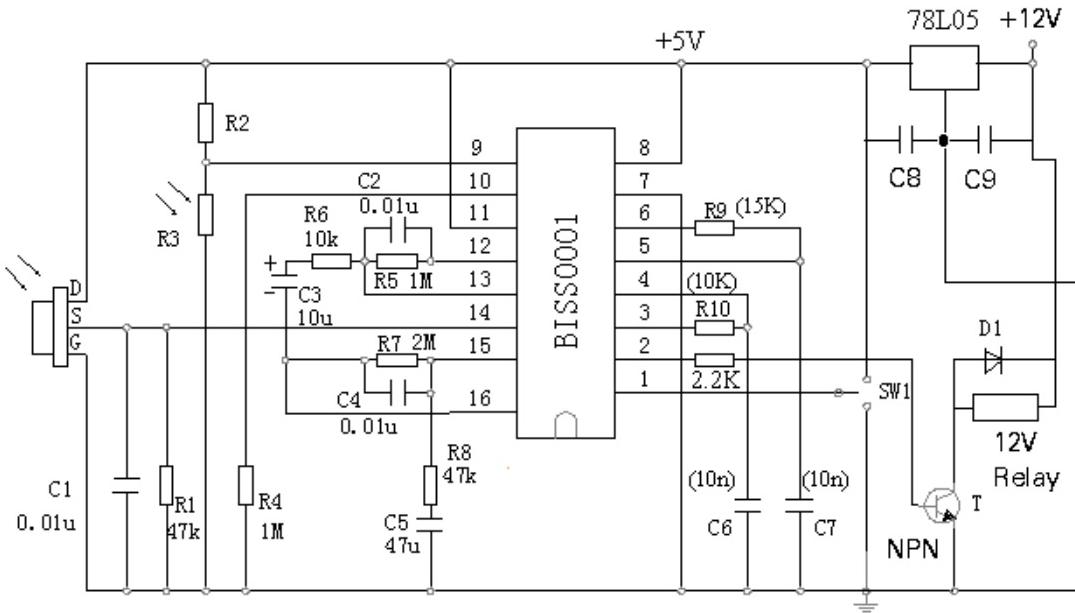


Figure 28: PIR Example Application Circuit (Image used with the permission of the Micro Power Corp.)

The example circuit has several features which were not necessary for our implementation. Specifically, we are already using a regulated 5 VDC power supply; therefore the voltage regulation portion can be removed. There is a light dependent resistor (R_3) connected to Pin 9 (V_C , the trigger disabled pin) used to inhibit the motion detector from working during the daytime. Since we require the motion sensor to be operational at all times Pin 9 was connected to V_{DD} ($V_C > 2V_{DD}$ enables operation). Also, the output of the decoder is used to bias a transistor which drives the coil of a 12 VDC relay; this portion of the circuit is also unnecessary for our application and was deleted. We also want the decoder to be retriggerable, which will continue to extend the time that the output will remain high as long as motion is detected. As a result, pin 1 was connected to V_{DD} . The duration of time that the output pin (V_O) remains high after trigger is calculated using the following equation:

$$T_x \cong 24576 * R_{10} * C_6$$

Since the fountain will remain active for four minutes after motion is detected, a value of nine hundred seconds will be used for T_x . The value for R_{10} is assumed to be 10 KΩ and the value of C_6 was calculated using as follows:

$$C_6 \cong \frac{T_x}{(24576 * R_{10})}$$

$$C_6 \cong 240 / (24576 * 10000)$$

$$C_6 \cong 0.9766 \mu F$$

A capacitor with a value of $1.0 \mu\text{F}$ was used. This value, which is slightly larger than the calculated value, provides a high output for approximately sixteen minutes.

To provide a 0.1 millisecond inhibit time between triggers (T_I) we used the following equation:

$$T_I \cong 24 * R_9 * C_7$$

A resistor value of $15 \text{ k}\Omega$ was used for R_9 and we calculated the value of capacitor C_7 as follows:

$$C_7 \cong T_I / (24 * R_9)$$

$$C_7 \cong .0001 / (24 * 15000)$$

$$C_7 \cong 277.78 \text{ pF}$$

A capacitor with a value of 270 pF was used. This value, which is slightly smaller than the calculated value, provides a trigger inhibit time of approximately 0.0972 milliseconds.

Placing the switch J1 in the position indicated in Figure 29 places 5 VDC on pin 1, which makes the decoder circuit retriggerable. The output, pin 2, was connected directly to the microcontroller to enable or disable fountain operations.

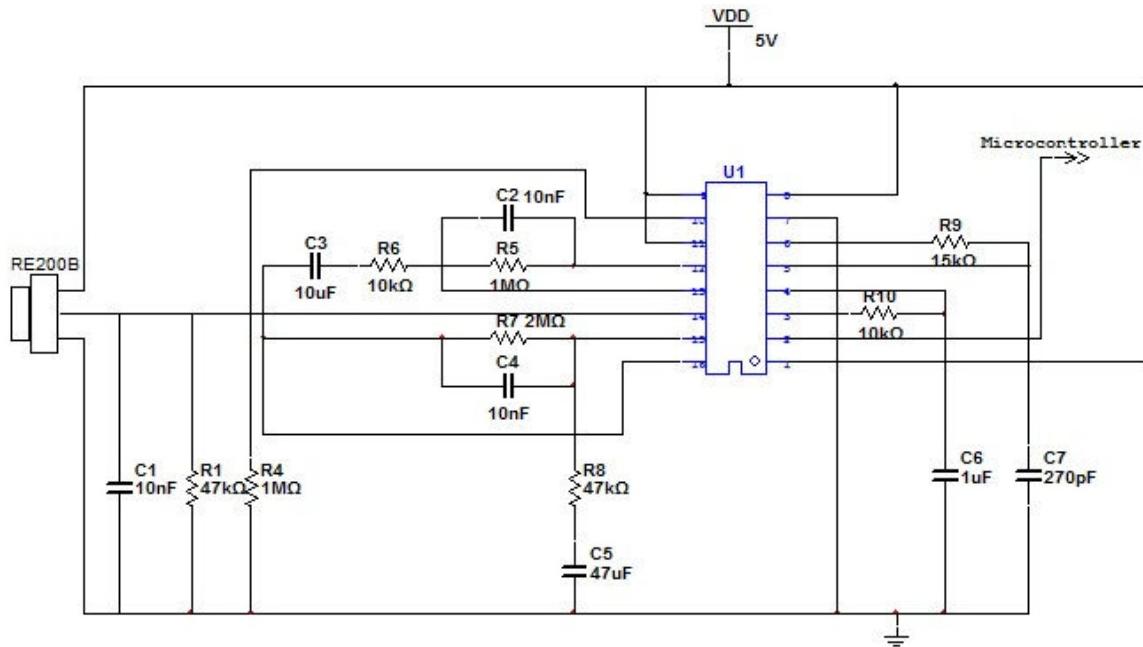


Figure 29: PIR Motion Sensing Circuit

3.2.6 Ambient Light Sensor Circuitry

We decided to use the phototransistor coupled with an operational amplifier as the basis of our day/night circuitry due to its faster response time, lack of memory, and its versatility to more easily interface with TTL level components. There are two varieties of phototransistor circuits, binary/logic and analog. For our purpose a binary/logic circuit provides the input to the microcontroller. In keeping with the desire to minimize energy consumption, the circuit is designed as a dark sensor. The reasoning behind this is that the circuit is energized for a longer period of time waiting for the light level to decrease enough for the LEDs to be visible. Minimizing the time the circuit is energized extends the usable lifetime of the circuit components.

The binary circuit detects the ambient light level and outputs a logic value corresponding to whether or not the level is above or below the set point level for detection. The circuit will be setup as an inverting circuit, outputting a logic “0” when the light is above the level of detection, or a non-inverting circuit, outputting a logic “1” when the light is above the level of detection. The circuit in Figure 30 includes a hysteresis function to minimize unnecessary switching of the circuitry if the light level fluctuates around the detection level. The circuit also allows the ability to more easily set the sensitivity level of the circuit than if a light dependent resistor were used.

U1A is an operational amplifier configured as a comparator. Potentiometer R1 is used to set the light detection level. A low resistance value (i.e. a few thousand ohms) sets a high detection level for the light to exceed before any switching can occur, making the circuit less sensitive. If a larger potentiometer were used, i.e. 100 K Ω , a low light detection level would be set, making the circuit more sensitive. Resistors R2 and R3 set up a voltage divider network that generates the reference voltage (V_{ref}) for the operational amplifier. Resistor R5 is a pull up resistor for the open collector output of comparator. Resistor R4 is used for hysteresis; with the use of hysteresis there is a dead band between light levels that switches between “0” and “1.” This prevents unnecessary switching if the light level is near the detection level; the smaller the value of R4 the larger the dead band between switching.

As light strikes the phototransistor, U2, it begins to conduct. The more light that strikes U2, the more it conducts. As the conduction of U2 increases the voltage at the non-inverting terminal (V^+) of U1A decreases. Once V^+ is below the value of V_{ref} the output of U1A switches to a logic “0” voltage level. When the light intensity striking U2 decreases, the amount of conduction of U2 decreases. This causes V^+ to increase, and once V^+ is greater than V_{ref} , the output of U1A switches to logic “1” voltage level.

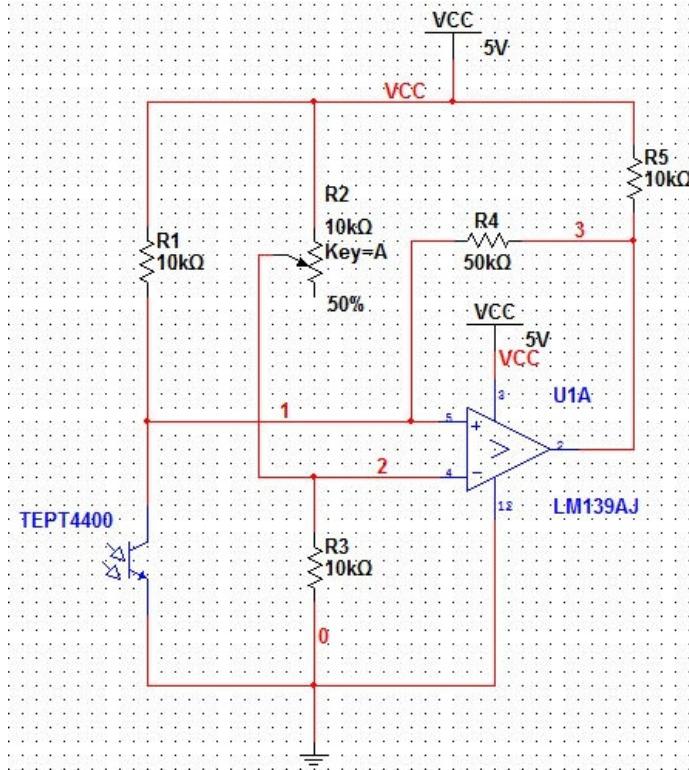


Figure 30: Day/Night Circuit

3.2.7 Servo Driver Circuitry

The servos used for the cutter mechanism require a .9 to 2.1 millisecond pulse repeated every 20 milliseconds (or 50 Hz) to control its position. A 1.5 millisecond pulse would put the servo at the midpoint position. Our original concept was to utilize the pwm outputs from the microcontroller but since the refresh rate of the servo control pulse is much slower than the clock of the microcontroller that was not a practical solution. Our final solution was to use a standard LM555 timer to generate our control pulses. These pulses used in conjunction with digital outputs from the microcontroller provided two position control of the servo. Since we only needed a cut and an uncut position for the cutter mechanism this schemed provided all of the necessary controls.

In this circuit LM555 is configured as astable multivibrator. The main timing capacitor, C1, is always charged to the voltage level which is determined by the voltage on LM555 pin 5 around 1.6V. When the timing capacitor is charged only with current coming through 33KΩ resistor, the charging takes around 2 milliseconds. When control voltage is applied from the microcontroller, the charging current increases when control voltage increases. When the capacitor is fully charged, LM555 starts to discharge the capacitor through 100K ohm resistor. The discharging continues until the voltage has reached the half of the control voltage ($1.6V/2 = 0.8V$). The discharge time is determined by the resistor between LM555 pins 2 and 7. The 100 KΩ resistor in this circuit makes this time to

be around 15 milliseconds. When the capacitor is discharged, the circuit starts charging it again.

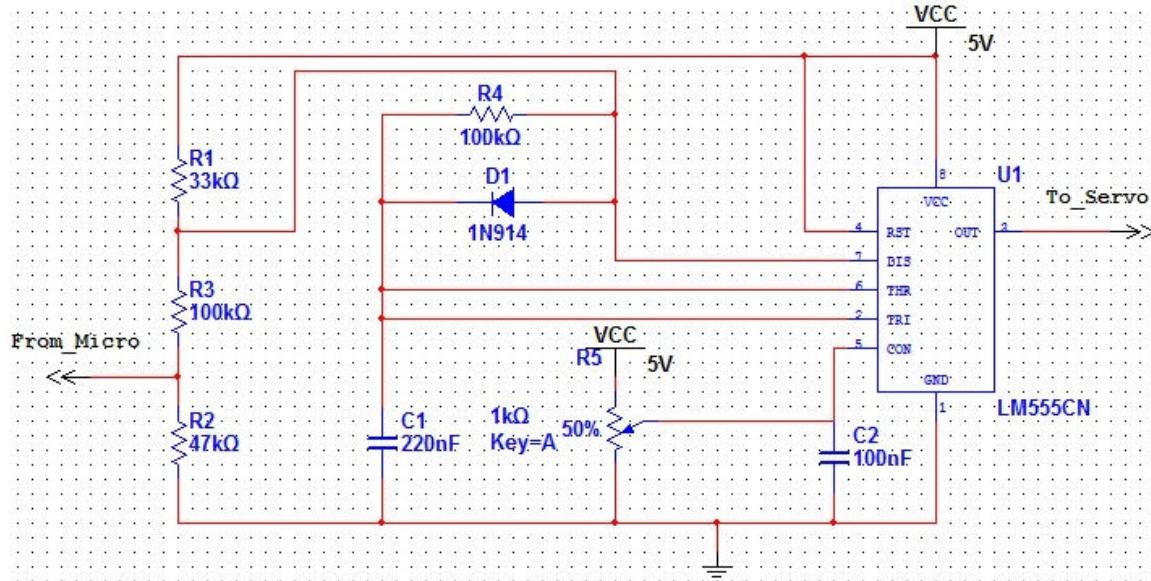


Figure 31: Laminar Flow Nozzle

3.2.8 Laminar Flow Nozzle and Cutter Mechanism

The nozzle is constructed from the following supplies obtained at local home improvement centers:

- 24" x 4" diameter SCH40 PVC pipe
- 24" x 25' vinyl screening
- 12" x 36" x 1/4" acrylic sheet
- 18" x 1/4" diameter stainless steel tubing
- 4 Packages of standard non-bending drinking straws
- Silicone sealant
- 24" x 1/4" diameter threaded rod
- 1/2" NPT water hose fitting
- 3/4" x 1/4" plastic cord grip fitting with locking nut
- (8) 1/4" nuts, washers and lock washers

We used the Laminar Nozzle, Outlet Plate, Inlet Plate, Servo Mounting Plate, Cutter Arm and Gasket drawings shown in future figures as a reference to construct the nozzle. Shown in Figure 31 is a complete drawing of the nozzle.

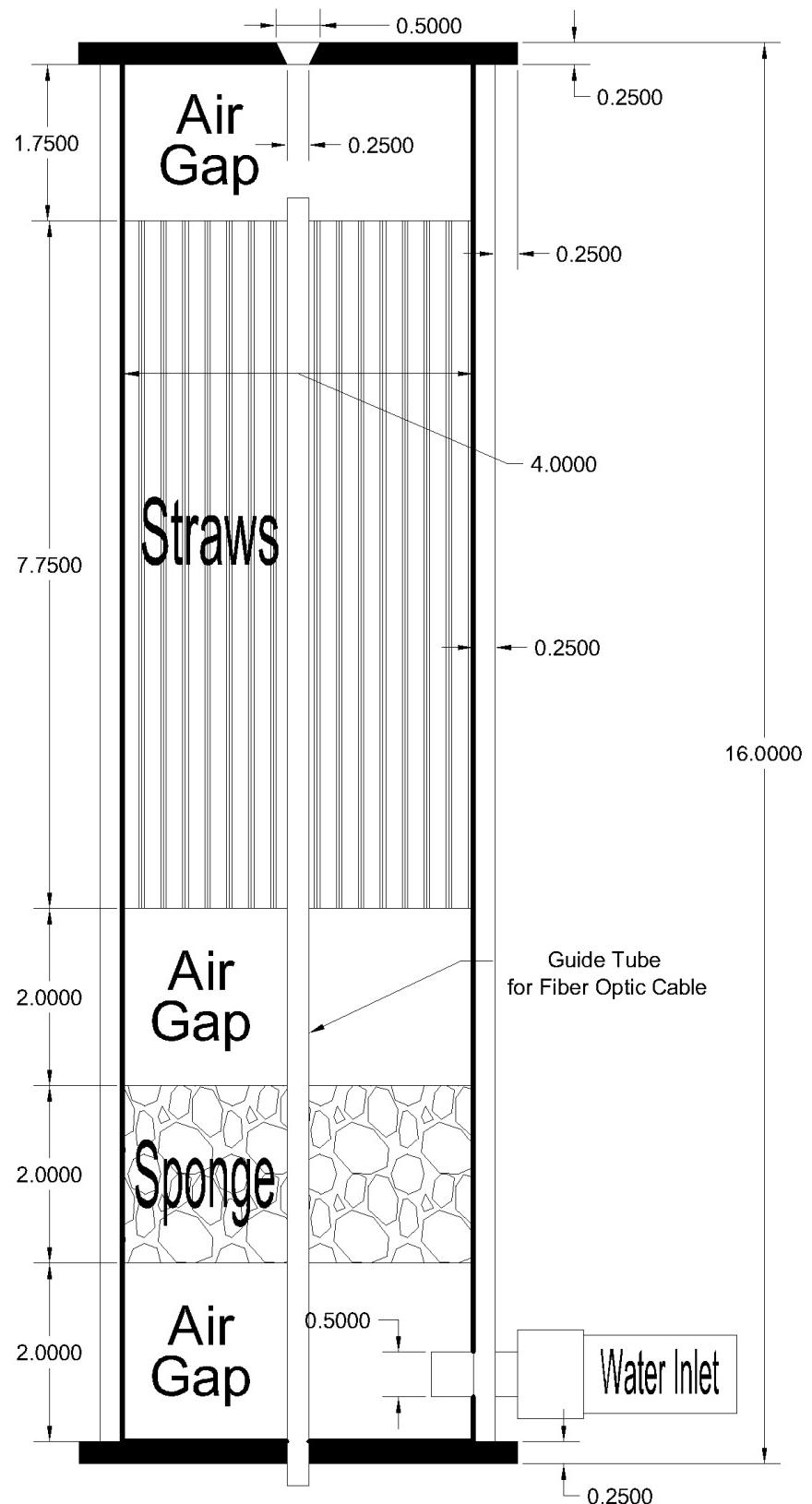


Figure 31: Laminar Flow Nozzle

The main body of the nozzle was made by taking the 24" long piece of 4" SCH40 PVC pipe and cutting it down to a length of 15 $\frac{3}{4}$ ". The remaining 8 $\frac{1}{4}$ " piece was used later on to create the internal retaining rings. After the body was cut to length, the end was sanded down slightly to remove any rough edges left over from the cutting process. This was done to ensure that the end is as "squared off" as possible to provide adequate sealing surfaces for the gaskets to mate up against. Using the leftover piece of 4" PVC from the body, we cut two 1 $\frac{3}{4}$ " long rings and one 2" long ring. These rings are used to secure the inner pieces of the flow nozzle. These rings also had all rough edges sanded off to prevent them from creating any turbulence inside the nozzle. At the drill press, we drilled a $\frac{1}{2}$ " diameter hole for the water inlet in accordance with the Laminar Nozzle drawing. The outlet and inlet plates for the laminar nozzle are shown in Figure 32 and Figure 33 below.

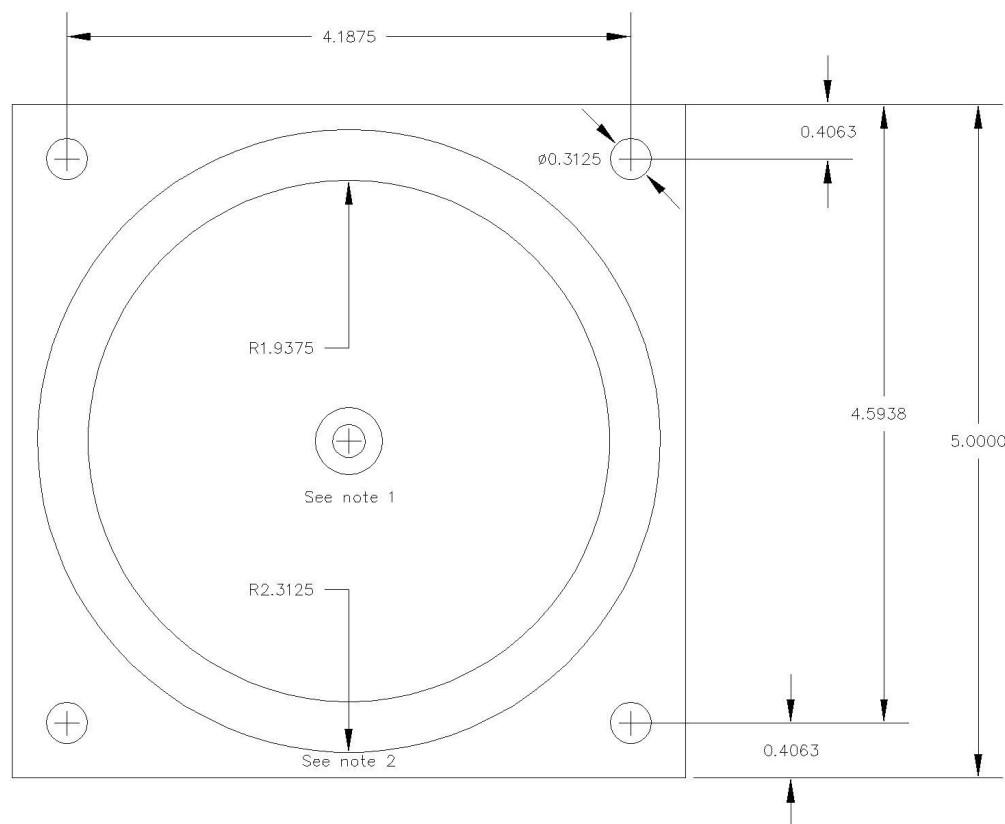


Figure 32: Outlet Plate for Laminar Nozzle

Note 1: Nozzle outlet is a tapered hole from a 0.5" diameter hole on the exterior to a 0.25" diameter hole on the interior side of the plate at a 45° angle.

Note 2: The sealing groove is cut on the interior side of the plate at a depth of 0.125".

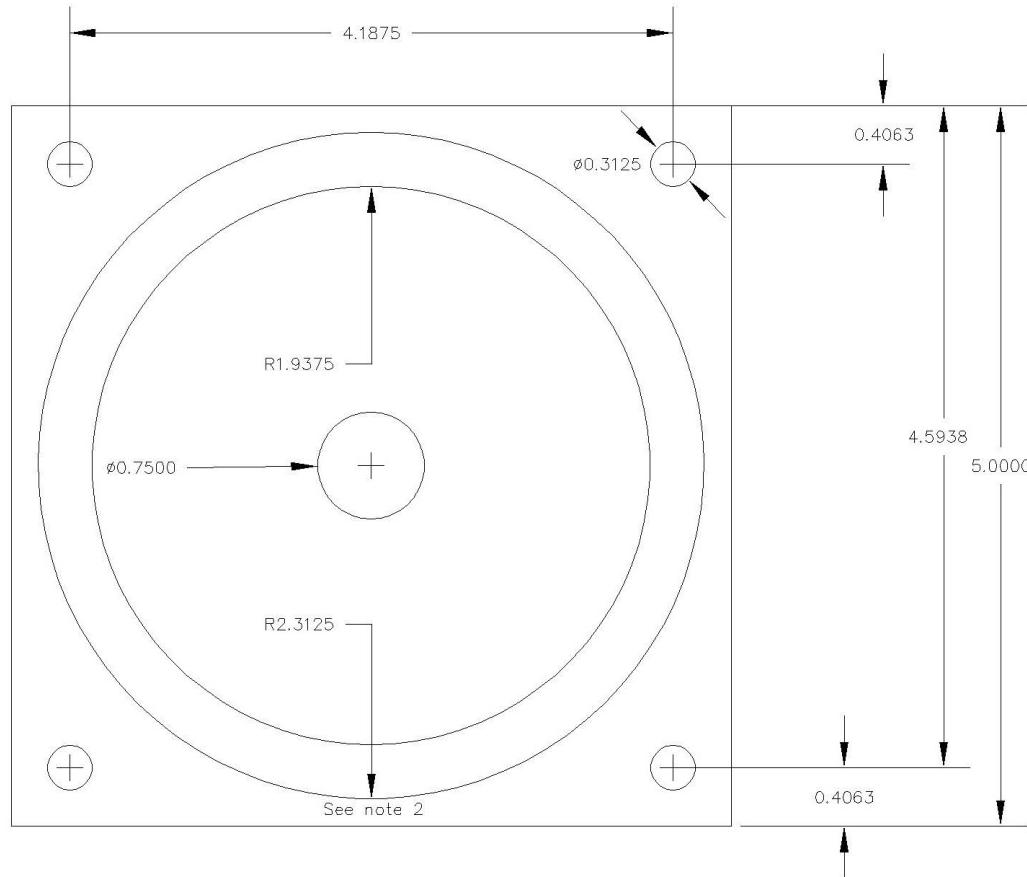


Figure 33: Inlet Plate for Laminar Nozzle

Using a band saw, we cut out three 5" x 5" squares from the acrylic sheet. We measured out and marked the four 5/16" diameter holes on all three plates. Using a drill press to ensure that the holes are drilled straight, we bored out all of the holes. Then, we measured out and marked the sealing grooves on the two end plates. Using a router or milling machine, we cut the sealing grooves out of the two end plates. After the grooves were cut, we ensured no leftover material or debris remained on the sealing surface. We then measured out and marked the center points of all three plates. At the center of the inlet end plate, we drilled a $\frac{3}{4}$ " hole and fit the cord grip fitting in the hole. We sealed around the cord grip fitting with the silicone sealant and locked it in place using the locking nut. This cord grip fitting holds the fiber optic guide tube in place and allows for proper positioning of the fiber optic guide tube. At the center of the outlet endplate on the exterior side (the side without the sealing groove), using the drill press, we drilled a tapered hole. The hole is $\frac{1}{4}$ " in diameter on the interior surface and $\frac{1}{2}$ " in diameter on the exterior surface. At the center of the servo mounting plate, we measured and marked a 1" diameter hole and the two servo mounting holes as per the Servo Mounting Plate drawing shown in Figure 34. We drilled out the holes at the drill press.

Using one of the retaining rings previously cut as a template, we marked out a 4" diameter circle on the sponge material. Then, using a long sharp knife, we cut out the circle from the sponge material. In the center of the sponge circle, we made a $\frac{1}{4}$ " slit. Next, we used a piece of paper or cardboard for a template and cutout a 5" diameter circle. Using this temple, we then cut out four 5" circles from the screening material. In the center of each screen circle we cut a $\frac{1}{4}$ " diameter circle. We made a single cut in the 2" retaining ring and slid it into the nozzle body. Then, we marked the distance of overlap and cut most of the overlap material off, leaving the ring slightly oversized to prevent cutting the ring too small. We placed the ring back inside the body and retried the fit until the ring just fits inside. Next, we removed the ring and centered one of the screen circles over the inlet end of the body. We slid the cut retaining ring into the body being careful not to tear the vinyl screen. Then, we continued to slide the ring into the body until the outer edge of the ring was 6 1/8" inside the body. Then, we placed a small bead of silicone all the way around the ring and smoothed it out with the tip of our finger and allowed the silicone to set.

Next, we slid the sponge circle into the nozzle body from the inlet end until it was just pressing against the already installed retaining ring. We verified that there was a 2 1/8" gap between the sponge and the inlet end of the body. Then, we cut a section out of one of the remaining retaining rings just large enough to accommodate the water inlet fitting. We centered a screen circle over the inlet end of the body and, with the section cut out of the retaining ring aligned with the hole for the inlet fitting, slid the screen and retaining ring into the nozzle body. We slid the ring into the body until it was flush against the sponge. We verified that the ring was $\frac{1}{4}$ " from the edge of the nozzle body. We then placed a bead of silicone sealant around the ring and smoothed it over. Then, we secured the inlet water fitting to the body. Figure 34 shows the Servo Mounting Plate, Figure 35 shows the Cutting Arm, and Figure 36 shows the Endplate Gasket.

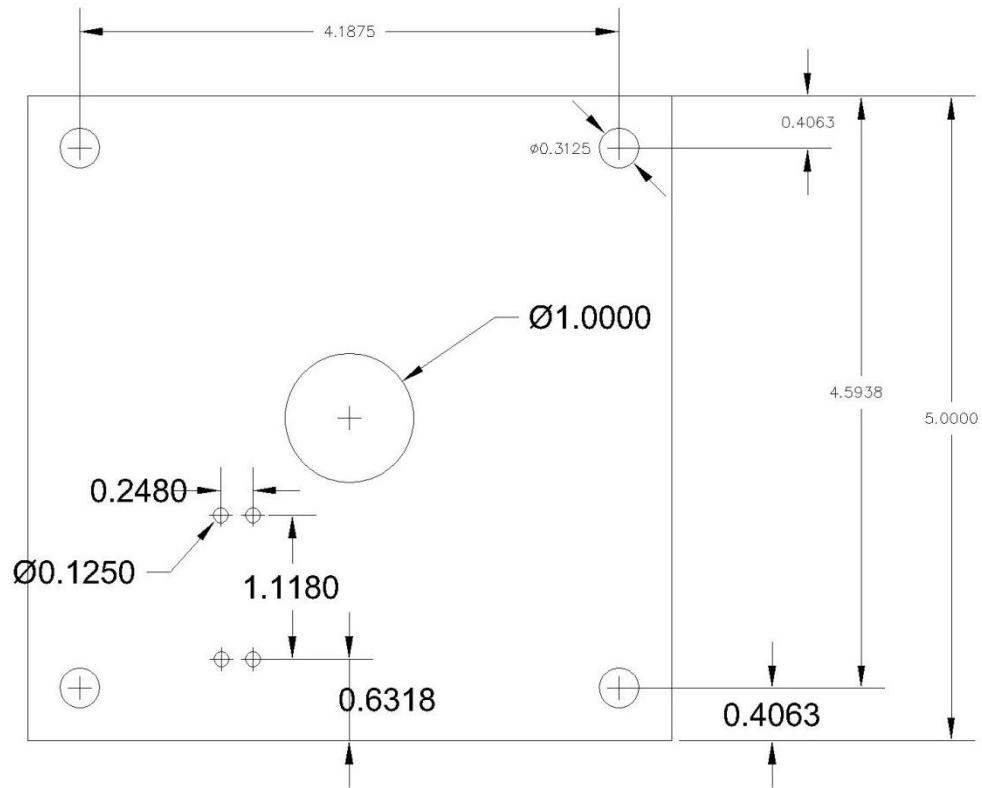


Figure 34: Servo Mounting Plate

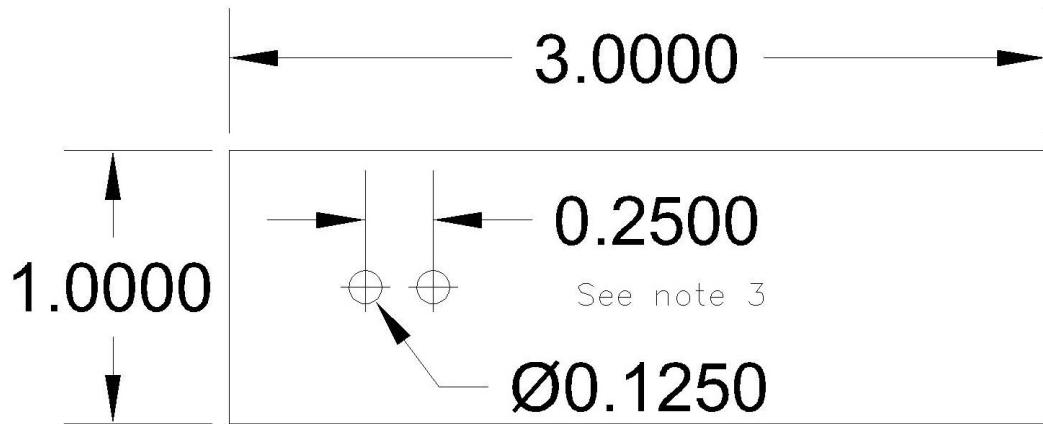


Figure 35: Cutting Arm

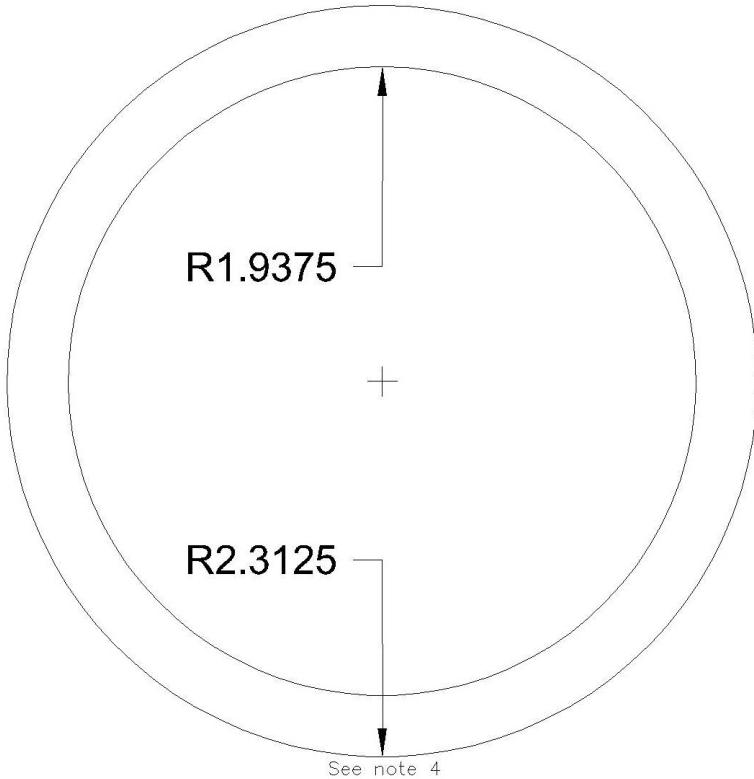


Figure 36: Endplate Gasket

Note 3: The cutting arm is made from 1/8" aluminum.

Note 4: The sealing gasket is made from 1/8" thick rubber gasket material.

Next, we slid the 1/4" stainless steel tubing through the cord grip fitting on the inlet end plate until it protruded approximately 14" past the interior side of the inlet plate. The final position of the tube was determined once all assemblies were in place. We then placed one of the gaskets over the end of the tubing and positioned it in the sealing groove of the inlet endplate. Then, we carefully inserted the tubing through the holes in the screens and sponge until the endplate and gasket mated up with the inlet end of the nozzle body.

At this point, we filled the nozzle with the plastic straws; ensuring that the straws were straight and not twisted inside the body. Once the straws were packed tightly in the body, we repeated the process of inserting a retaining ring and screen against the straws. We then slid the three fiber optic cables inside the stainless steel tubing until they extended 1/4" beyond the end of the tubing. We used a silicone sealant to seal the end of the tubing around the fiber optics without getting any on the polished end of the fiber optics. We placed the remaining gasket in the sealing groove of the outlet nozzle and placed the endplate on the outlet of the nozzle body. Next, we placed a flat washer, lock washer and nut on the end of each piece of threaded rod. Following this, we inserted a threaded rod through each of the corner holes of the inlet plate and

then out through the holes of the outlet plate. Next, we placed a flat washer and lock washer on each thread rod and ensured that they were resting on the outlet plate. We threaded a nut down each rod until they were hand tight against each lock washer. We alternately tightened each nut until a solid seal was achieved and allowed the silicone sealant to completely set before testing the nozzle.

While the silicone sealant was setting, we mounted the servo motor to the servo mounting plate and fastened the cutting arm to the servo motor shaft. We then threaded a nut down each thread rod until each nut was $\frac{3}{4}$ " above the outlet plate. We placed a lock washer and then a flat washer down each threaded rod and slid the servo mounting plate down the threaded rods. We then placed a flat washer and lock washer down each threaded rod and then threaded a nut down each rod until the mounting plate was securely fastened to the nozzle. Finally, we made the electrical connections between the servo motor and the microcontroller. The cutting mechanism was then ready for testing.

3.2.9 Fiber Optic to LED Interface

In order to transfer the light from the LED's to the laminar flow cutter we designed a LED/Fiber coupler. The coupler sits over the LED and creates an interface between the LED and fiber cabling. Through this coupler the light from the LED travels down the fiber cabling to the laminar flow cutter. At that point the light is transferred to the water.

3.2.10 User Interface

The user interface consists of both primary and secondary systems. The primary user interface is the infrared remote control. For our project, we are utilizing a programmable universal remote control. We chose the Philips Pronto TS1000 for its versatility and due to the fact that we obtained one for free. The Pronto has a 3.8" diagonal touch screen. The touch screen has a resolution of 240 x 320 pixels with four color grey scale. It has 1 MB of non-volatile flash memory, 512k SRAM, a serial interface, infrared code learning and an infrared operating range of approximately 33 feet. There are seven programmable access buttons and a built in light sensor that automatically turns on the backlight in low-light environments. The sensitivity of the light sensor was adjusted to suit our needs. Through the use of the Pronto Edit, graphical editing software, we were able to create any type of control panel or menu driven system we desired to control the fountain. This remote has the capability to allow the user to create macros and timers to send control sequences to the microprocessor. Using this remote control allows us to create and label all the buttons and menus we require for our current project, and any future additions that we may make in the future can easily be programmed into the remote. The Pronto TS1000 is able to learn IR codes from existing remotes or we can generate our own codes and program them into the remote and assign them to any button, graphical or direct access, we choose. Using this remote allows us to ensure that the remote provides all the functionality that we want and allows the interface to be customizable to almost any user specification.

The secondary portion of the user interface consists of various electromechanical switches, from DIP to rocker switches. Using appropriately sized rocker switches, we have enabled the user to turn ON and OFF the entire system by removing the 120 VAC power that feeds both the 5 VDC power supply (which feeds all of the electronic circuitry from the microprocessor to the low water level sensing circuitry), and the centrifugal water pump. Another rocker switch is used to de-energize the 5 VDC power supply but allow the centrifugal pump to continue to operate. This switching combination allows the user to de-energize all or part of the system for various user needs and troubleshooting.

DIP switches make up a bulk of the secondary user interface. While we could have purchased one continuous block of switches to satisfy the entire project requirements, we chose to break the DIP switches into smaller blocks. The reason for breaking the DIP switches into smaller blocks is to aid the user in identifying the appropriate switch. By using blocks of six we can separate the six preprogrammed selector switches from the six individual LED ON/OFF input switches. With switches being relatively small and close together, it is sometimes difficult to actuate the correct switch in a long block of DIP switches; this design choice alleviates this problem. The final block of six DIP switches is used to select manual or automatic operation and provides spare switch positions for future system expansion if desired.

Two momentary pushbuttons round out the last of the switch portion of the user interface. When the system is placed in manual mode, the pushbuttons provide the user with the means to control the individual nozzle cutter mechanisms. By using non-locking momentary pushbuttons we ensure that the nozzle cutting mechanisms cannot be unintentionally blocked and require a constant user input to block the streams exiting the nozzles.

3.2.11 Pump Control Circuitry

The pump control circuitry is responsible for protecting the pump from running dry, a condition that would significantly reduce the life of the pump. The circuit contains a relay that operates in normally closed position. The normally closed relay allows the pump to remain active while water levels are considered at a safe level. When the water level drops, a float switch deactivates the normally closed circuit and turns off the pump. This circuit is also responsible for ensuring the microcontroller does not run when there is no water output. This circuit was designed to run off the 5 volt DC power supply. The circuitry turns off the pump when water levels fall below 6 inches to prevent the pump from running dry.

The pump control circuitry consists of a primary and secondary circuit. The schematic shown in

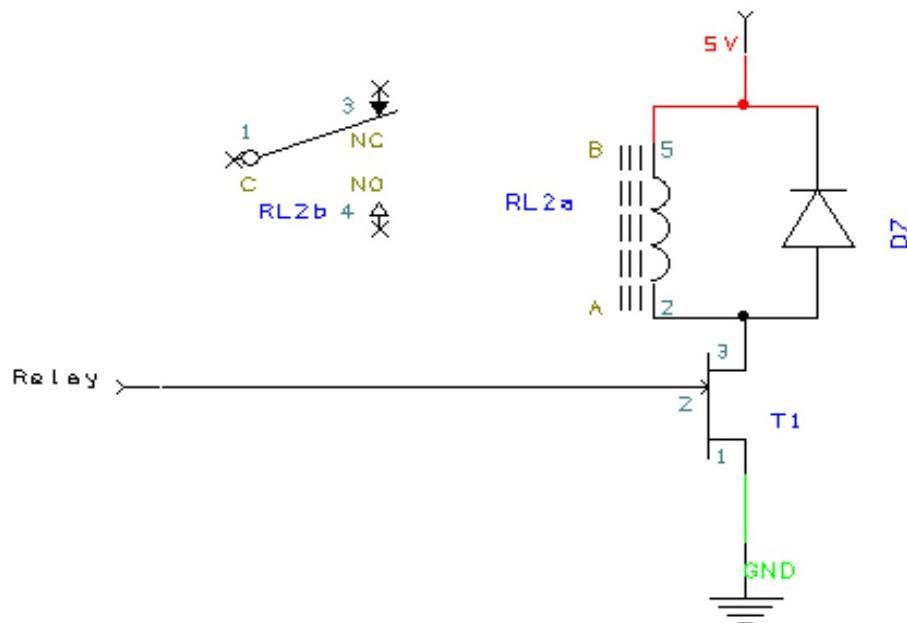


Figure 37: Relay Driver

was used for the basis of the pump control circuitry. If the water level falls below 6 inches the float switch opens and triggers the RB0/INT switch on the microcontroller. This in turns opens the relay which turns off the pump. When a satisfactory water level has returned the software returns from the interrupt subroutine and then reinitiates the pump and program to normal operation.

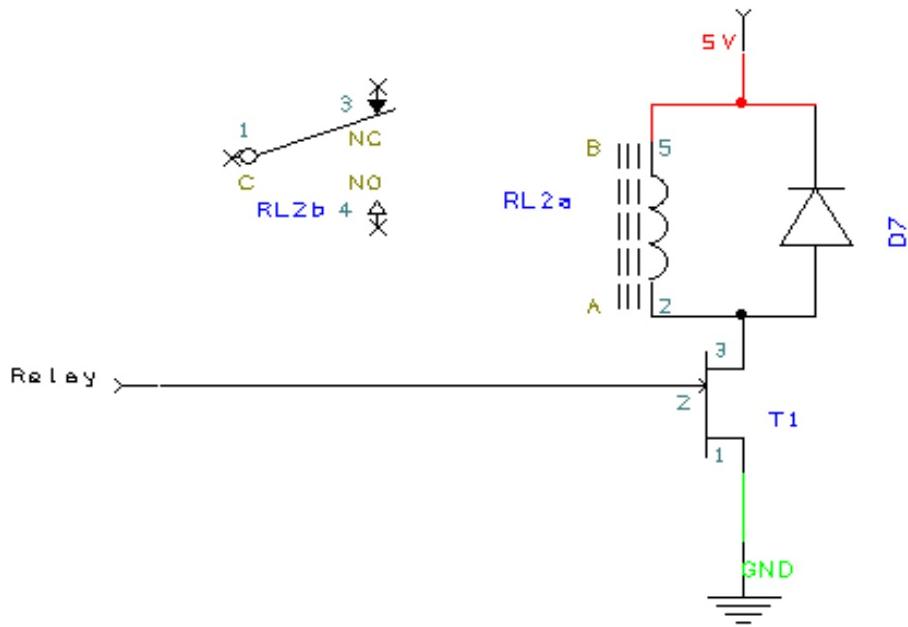


Figure 37: Relay Driver

3.2.12 Printed Circuit Board

Although we were unable to fully design the PCB before the December 14, 2009 deadline for the paper we knew that we would fabricate our PCB through 4PCB. 4PCB has a student special consisting of one PCB with a maximum area of 60 square inches that costs only \$33.00 plus shipping. Our PCB was laid out in early January using the software provided by 4PCB. This software claims to have the largest parts library available from free software solutions. However after utilizing the software, we found that this wasn't true. We had to manually enter in a majority of the footprints for our design. These footprints were then linked to a schematic symbol which, for the most part, were each included in the software. Then, once each schematic symbol and footprint were created, we combined them into a symbol. We entered a complete schematic into the software. Once the schematic was complete, we were able to choose an option for the software to convert the schematic to a PCB design, optimizing the layout of the board. Once this was complete, we cleaned up the design, partitioning the board so that it was easy to navigate once we received it back from manufacturing for ease of solder.

Before sending the PCB to fabrication we had to be sure all designed circuits work as indicated though simulation. This was done by bread boarding all circuits before PCB fabrication.

Our board was a 2 layer, one sided board made from FR-4. The general layout of the circuitry is shown in Figure 38 below. The top layer consists of all components and the signal runs. The bottom layer contains the ground plane.

We used as many through hole components as possible to allow for easy soldering.

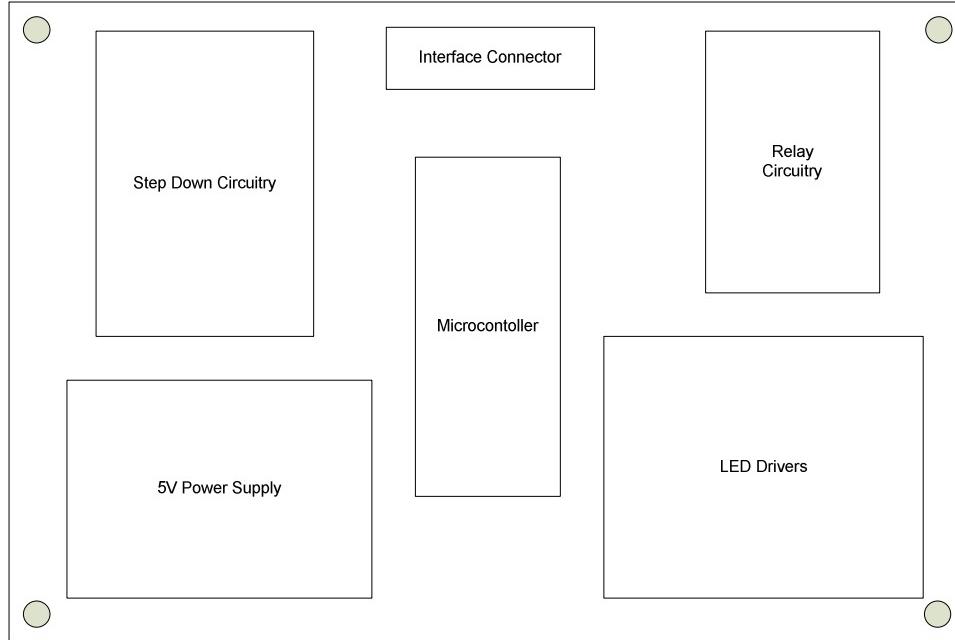


Figure 38: PCB preliminary Layout

3.2.13 Enclosure

The enclosure is an off the shelf part that is made from a non-rusting material and has a removable/hinged lid for testing and troubleshooting purposes. The max dimensions for this enclosure were not to exceed 40"x21"x7". Fortunately, we were able to obtain this enclosure at no cost. It comfortably houses our PCB, DIP switches, pushbuttons, and other circuitry.

3.2.14 Software

Software for this project was developed using MPLAB, the free development software provided by Microchip. Because of the availability of open source code on the internet we developed the code using assembly language. We programmed our Microchip in a block fashion.

The first block of program we developed was the cutter control. We wanted the code to be able to drive the servos of the cutter in 2 directions to open and close the nozzle. We are using 2, of the 4 PWM I/O pins, RD5 and RD6, in order to control the cutters. By varying the pulse widths we are able to vary the amount of time the cutter is open and the amount of time the cutter is closed. There are four variations in which the cutters are driven. We also have one variation that keeps the cutters open continuously so that the user can better see the LED's light up the laminar streams of water. Using the development board, we are outputting the pulse width modulated signals to LED's, allowing us to see the

modulation. Then, once we were satisfied with the visual PWM outputs we continued on to the next block of the program.

Next, we developed the LED driver block. This consists of the development of 4 separate programs that turn off and on the LEDs in order to color the water from the nozzle. The red, blue, and green lights are mixed in order to create a wider range of colors. The chosen LED program runs in a continuous loop until a new program is chosen by the user. Once the first 2 blocks of software were developed we combined them to run together so that the cutter and LEDs are running at the same time for each of the four programs. After this, we wrote the code for monitoring the peripherals. The signal for the Passive IR and the Ambient Light sensors is ANDed together and the microcontroller only executes a user chosen program if the output from the AND gate is a 1. This ensures that programs are only run when the user can see the Dynamic Liquid Light Fountain in its best visual display.

The program also requires an interrupt to be acknowledged if the ANDed output from the IR sensor and Ambient Light Sensor goes low for longer than 5 minutes. This is monitored and timed using a clock. If at any point during the 5 minute countdown the ANDed output goes high the timer restarts its countdown. The final block of code that was written allows the user to play music. The microcontroller then filters the music frequencies and, depending on the frequency, the LED's are driven in a pattern in order to create a display that appears to dance with the music. This will not require use of code to drive the cutter mechanism but just to drive the LEDs depending on the frequency of the music played.

4 Testing

Testing was completed in phases. The first phase of testing consisted of circuit simulation. The circuit simulation was conducted in tandem with the design phase of the project. Once circuitry was simulated and was functioning within the outlined parameters we bread boarded the circuit. While the circuit was bread boarded, we verified that the circuits still functioned within the given specifications and that the actual circuit functions the same way as the computer simulated circuit. We then put the finalized circuit into a schematic capture tool, 4PCB's free software. This tool allowed us to create the necessary files for PCB fabrication. Once the PCB was obtained from the board house we again tested the circuitry. The following section explains what measures we took to test the various pieces of the dynamic liquid light fountain before the final testing phase.

4.1 Safety Procedures

Testing was conducted in the Senior Design Laboratory. We adhered to normal UCF lab safety processes. To minimize the risk of electric shock we followed these guidelines. We avoided all contact with capacitors in energized circuits. We also took precautions to remove all conductive hand jewelry before working with electricity. When problems occurred in our circuitry, including shorts and opens, we first removed power and conducted resistance checks to try to find the faulty components. Because components have the potential to become hot and burn the skin, we avoided touching them for a minimum of 3 minutes after power was removed.

4.2 PCB Testing

Once the PCB returned from fabrication we took a series of steps to ensure proper fabrication.

The following steps were taken before components were installed on the PCB:

1. Visual Inspection of PCB runs. Avoiding unnecessary contact with copper runs.
2. Using an ohm meter ring out power and ground lines, ensuring no inadvertent grounding of power runs.

After part installation:

1. Conduct visual inspection of the solder joints.
2. Conduct ohm checks to ensure proper power and ground.

After all ohm and visual tests were conducted we tested the individual circuits as indicated in the following sections. The individual circuits were checked using the isolation switches placed on the PCB. These switches enhance the trouble shooting and testing process. For example, between the transformer, which

converts 120VAC to 5VDC from wall power, and the 120VAC source, we placed a switch that can isolate the 5VDC. There is also a test point on the output of the voltage regulator to allow us to verify the regulated output voltage.

4.3 Power Supply

The first thing we did in order to properly test our power supply was to determine the different tests that were recommended. Most of the test definitions can be found in greater detail in the IEC 60050 and the IEEE 100 documents. The different tests, definitions, and conditions include, but are not limited to: Active Mode, Active Mode Efficiency, No Load, No Load Power, Unit under Test, Ambient Temperature, Power Factor (True), Total Harmonic Distortion (THD), Apparent Power (S), Instantaneous Power, Active Power (P), Nameplate Input Voltage, Nameplate Input Frequency, Nameplate Output Voltage, and Nameplate Output Current.

The Active Mode is the condition where the input of the power supply is wired to the AC line voltage while the output is wired to the DC load drawing part of the nameplate power output of the power supply that is greater than zero. The Active Mode Efficiency is actually a ratio that is expressed as a percentage of the total real power DC output that is produced by the power supply to the real power AC input that is required to produce the voltage. See IEEE 1515-2000, 4.3.1.1.

The No Load condition is where the input of the power supply is wired to an AC source that is consistent with that of the nameplate AC input voltage of the power supply. The difference is that the output is not connected to any loads in the system. The No Load Power can be better referred to as the efficiency and by definition be zero (0) when calculated by using percentages. For this procedure the No Load Power is defined by using the wattage of real AC power being consumed in the No Load condition by the power supply. The Unit Under Test (UUT) is the condition where the power supply samples are being tested. The Ambient Temperature is considered the outside ambient air temperature that is surrounding the UUT. The Power Factor (True) can be represented as a ratio of the real, or active power (P) watts that are consumed by the apparent power (S), designated as volt-amperes (VA). The definition below of the power factor includes both the effect of displacement and distortion.

$$PF = \frac{P}{S}$$

The Total Harmonic Distortion (THD) is a ratio that can be expressed as a percent of the Root Means Squared (RMS) value of the fundamental component. The below equation represents the ratio where the I_{13} is equal to the RMS value of the 13th current signal harmonic:

$$THD_I = \frac{\sqrt{(I_2^2 + I_3^2 + I_4^2 + I_5^2 + \dots I_{13}^2)}}{I_1}$$

The Apparent Power (S) is a product of RMS current (VA) and the RMS voltage. The Instantaneous Power is a product of the instantaneous current and the instantaneous voltage at the terminal pair of the load or the port. The Active Power (P) is the RMS value of instantaneous power that is taken over a given period of time. Most meters or measuring equipment take an average of active power during a number of periods or cycles. The Nameplate Input Voltage is the specified AC input voltage of the power supply given by the manufacturer on the label or housing on the power supply. This voltage is most often given as a range voltage. The Nameplate Input Frequency is the specified AC input frequencies of the power supply also listed on the housing by the manufacturer. Most power supplies have several different frequencies listed.

The Nameplate Output Voltage is much like the input voltage and is specified, but it can be expressed as either AC or DC depending on the use of the power supply. In our project our output voltage is DC. The difference is that the output voltage is determined by the actual inputs and current applied to the power supply and the outputs may vary from the specified amount. The Nameplate Output Current is the specified current by the manufacturer listed on the housing, but the listed amount is a range that the power supply can operate without damage or failure. Our supply can operate at a max peak output current of 4 amps but is rated for a continuous output current of 3 amps. The loading amounts for the power supply can be determined by multiplying the nameplate output current amount by 100%, 50%, or 25%.

4.3.1 Testing Conditions

The conditions for testing were performed using the following constants: The Measuring Equipment, the Testing Room, The Test Voltage, The Input AC Reference Test Voltage, and the Test Leads. These conditions must be a constant or the process of testing and calculating is more unpredictable.

The measuring equipment for the power measurements was fabricated by a calibrated voltmeter and ammeter, but can also be effectively taken using a power analyzer and oscilloscope. As we can find specified in IEC 62301, the measurements of active power of about 0.5 watts or greater needs to be calculated using an uncertainty factor of greater than 2%, while active power measurements with less than 0.5 watts has an uncertainty factor greater than 0.01 watts. For our project we have a voltage greater than 0.5 watts so we use a 2% correction factor.

The testing room is a controlled room and can be specified in IEC 62301. All tests are performed in a room that has an air speed close to the UUT of less than 0.5 m/s with the ambient temperature being maintained at around 23 degrees Celsius for the entire test. The use of an externally powered fan, heater, or air

conditioner was avoided. The UUT is tested using a thermally non-conductive flat surface. The Test Voltage should be an AC source that supplies constant input voltage to the UUT and can be specified in IEC 62301. The UUT input voltage and frequency are specified with a variance of 1%. The frequency and voltage of our project are approximately 115 VAC at 60 Hz as stated on the nameplate voltage and frequency combination. The Input AC Reference Source Voltage should be capable of producing and delivering at least 10 times the nameplate input power to the UUT that can be specified in IEEE 1515-2000. The AC source type is not as important as the stability of the input so for this project are using a normal household outlet. The THD of the supplied voltage to the UUT should not exceed 2%, including the 13th harmonic specified in IEC 62301. Also specified in IEC 62301, the peak value of the test voltage is kept between 1.34 and 1.49 times the RMS value.

The Test Leads used for the measurement equipment are just as important if not more important than the equipment itself. The leads should be constructed of a large enough gauge and short length that it does not affect the readings and to avoid the introduction of induced voltage errors in the testing process. In IEEE 1515-2000 table B.2, “Commonly used values for wire gauges and related voltage drops” can be used to verify the correct wire gauge is used.

4.3.2 Measuring Approach

The first step in the measurement approach was to prepare the UUT for testing. If there are any internal switches on the UUT that control the power flow to the AC input, they were turned to the “ON” position. The power supply packaged for consumer use should have a hard wired power cable provided by the manufacturer with the proper gauge cables and wiring. We have several options available for connecting measuring equipment to the output of this power supply. The option we chose is to cut the cord immediately outside of the adjacent connector and attach the leads of the equipment to the stripped wires.

We are also able to test the efficiency of an open circuit board power supply before it gets implemented into the finished enclosure and the connection of its DC output wires. It is important that no matter what configuration you test in the power supply, it must be tested in its final configuration in order to accurately represent how it will function during the demonstration.

We simulated the load conditions as accurately as possible. Most all single voltage external power supplies have some sort of nameplate output current. The values are calculated by using the table below. These are the values used to figure out the four main active mode load conditions and also to no load condition. We ensured that the UUT was tested using all the load conditions found in Table 5 below.

Percentage of Nameplate Output Current	
Load Condition 1	100 % \pm 2%
Load Condition 2	75% \pm 2%
Load Condition 3	50% \pm 2%
Load Condition 4	25% \pm 2%
Load Condition 5	0%

Table 5: Test conditions for power supply

While testing we remembered the 2% allowable variance from the nameplate output current and not just the one we calculated. We could have for example tested the UUT at “Load Condition 3” by testing within the range of 48% to 52% of the rated output current. In IEEE 1515-2000, it notes that we can test additional load conditions, but these were not really required as part of this procedure. A set-up of the load conditions applied to the power supply is shown below in Figure 39 .

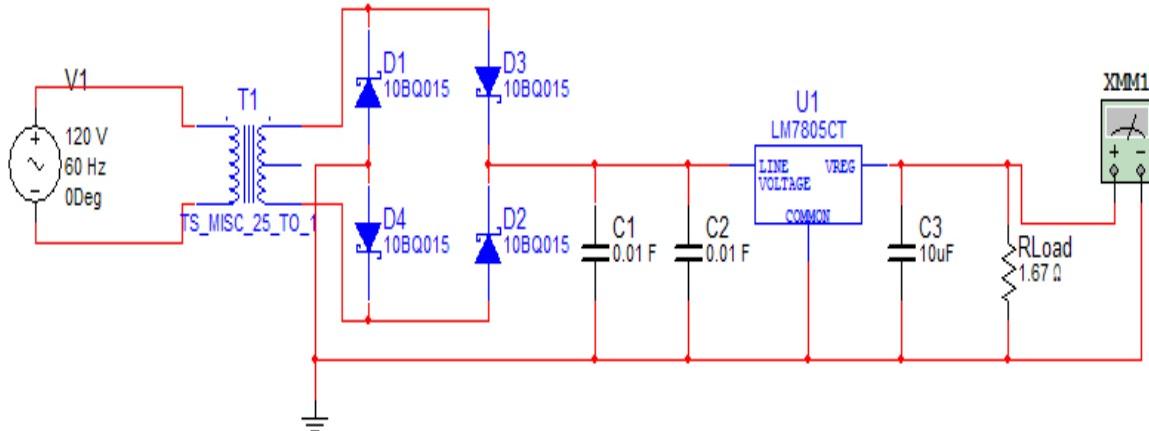


Figure 39: Simulation of load conditions

The loading guideline was calculated in order to properly load the power supply while producing all four of the active mode loading conditions. We purchased 1 and 10 ohm, 5 and 2 watt resistors from Radio Shack to obtain the proper load of approximately 3 amps. Even though the power supply is designed to operate using different load characteristics, resistors provide a standardized reference for testing multiple times and for different product comparison. The resistive loads don't necessarily need to be exactly measured by an ohmmeter because if you have a variable resistor, it can be adjusted to the point where the ammeter reaches the desired percentage calculated using the nameplate output current. However, it was simpler, cheaper and quicker to purchase resistors from Radio Shack for testing purposes.

Shown in the figure below is the simplified schematic using an external power supply testing set up while applying a variable load resistance. While testing, the desired output current is adjusted in the constant current mode instead of just

adjusting the required output power in constant power mode. Below Figure 40 showing the configuration of our testing equipment in order to properly test the UUT:

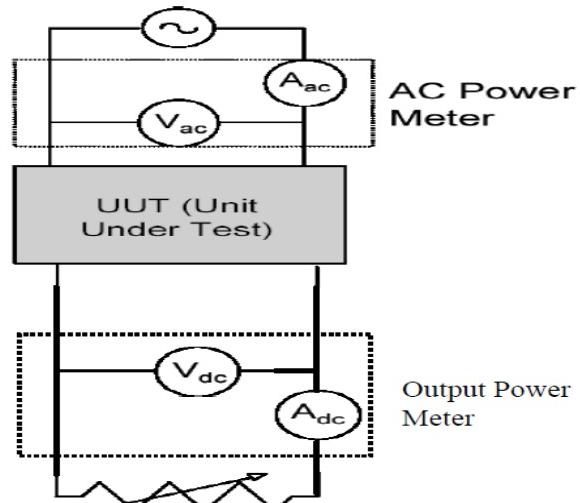


Figure 40: Correct set-up of testing equipment

While choosing the proper testing sequence it helps to consult the IEC 62301, which states that instantaneous measurements are only acceptable when the power readings are stabilized using a particular load condition. Upon conducting efficiency measurements the UUT should be operated at 100% of its nameplate current output for no less than 30 minutes to verify all is functioning properly.

After the power supply has had this warm up period, we maintained the AC input power for a duration of about 5 minutes in order to properly asses the stability of the UUT. If there was no power drift noted that exceeded 5% from the maximum value observed, we may consider the UUT stable and the measurements were accurately recorded at the end of the 5 minutes. We continued to do this method for all of the load conditions. The 30 minute warm up period was required each time you break for longer than an hour or so.

If the AC input power was unstable during the 5 minute duration, we must consult the guidelines established in the IEC 62301 for measuring an average power or an accumulated energy over a given time for both the DC output and the AC input. The efficiency measurements were tested using the sequence of load condition 1 to load condition 5 shown in the table above. We calculated the efficiency by dividing the measured active output power of the UUT at any given load condition by the active AC input power measured at that load condition. The efficiency average is calculated by the arithmetic mean of the efficiency values calculated by test conditions 1-4 in the above table. This is not intended to represent the weighted average efficiency because it is just a simple arithmetic

average of the active mode values. The values can vary according to the duty cycles of the devices powered by the power supply.

As part of the parameters we looked for we calculated the consumption of power of the UUT at each of the load conditions 1-4. The power consumption is the difference between the active output power at the given load condition and the AC active input power at the specified load condition. For example, we calculate the consumption of power at load condition 5 having no load, is equal to the AC input active power at the given load condition.

As we followed through the testing procedures it was important we followed a certain path for recording test data. The test report data includes the UUT manufacturer, the UUT Model Number, the UUT Output cord length, the location of any internal/external switches, the known loads and hardware, the nameplate information, scaled pictures of the power supply, the ambient temperature around the UUT, date and location of test, and the test equipment information. It's important that when testing, we record the key data that is both calculated and measured such as the voltage and frequency at each load condition. Below is a table that summarized the recommended collection of the data.

Reported Quantity	Description
Rms Output Current (mA)	Measured at Load Conditions 1 – 4
Rms Output Voltage (V)	
Active Output Power (W)	
Rms Input Voltage (V)	Measured at Load Conditions 1 – 5
Rms Input Power (W)	
Total Harmonic Distortion (THD)	
True Power Factor	
Power Consumed by UUT (W)	Calculated at Load Condition 1 – 4, Measured at Load Condition 5
Efficiency	Calculated at Load Conditions 1 – 4
Average Efficiency	Arithmetic Average of Efficiency at Load Conditions 1 – 4

Figure 41: Values tested in order to verify the Power Supply is operating correctly

By using the table above, we easily compared our test data to the other recorded data and also our calculated amounts. Another way to display usable data is to display it in a graphical form, easily done in Excel. A good sample format for this can be found in IEEE 1515-2000, section 4.3.1.2 in figure 10, the “Input vs. Output Power” chart. By using the graphical format we have a useful way to show a power supply’s relative efficiency, which includes the AC active input power and the active output power using 100%, 75%, 50%, 25%, and zero percent of the nameplate current output.

At the conclusion of our testing, we evaluated whether or not the power supply was performing correctly. It was imperative that the power required for the DLLF is provided efficiently and safely from our power supply. If any of the conditions

were unstable, we would have reconsidered our design and implemented changes to hardware where necessary.

When we first constructed our power supply with the appropriately rated heat sink, we verified the output voltage at half load, or 1 ½ amp. The output voltage was 5.24V. We ran this test, taking voltage measurements every 10 minutes, until the power supply had been on for about an hour. At each increment, the voltage measured exactly 5.24V. Thus, we knew that the power supply was operational at 50% load. After this, we added more load resistors to bring the load up to 100% at 3 amps. Even though this is about 150% of our actual load, we wanted to make sure that the power supply was more than adequate for our project, including any unforeseen additional required circuitry that was added. At 9:08 pm, our output voltage was 5.02V with a 3 amp load. Again, we took voltage measurements at 10 minute intervals to verify that the voltage regulator was not overheating, thus verifying that our heat sink was sufficiently rated. At 9:18 pm the output voltage was measured at 5.04V. Again, at 9:28 pm the output voltage was measured at 5.03V. We continued this test until 10:08 pm at which time the voltage was measured at 5.03V. Thus, our power supply testing phase was complete and we were confident that the power supply we designed and constructed will power our electronics safely. Shown in Figure 44 is our simulated load.

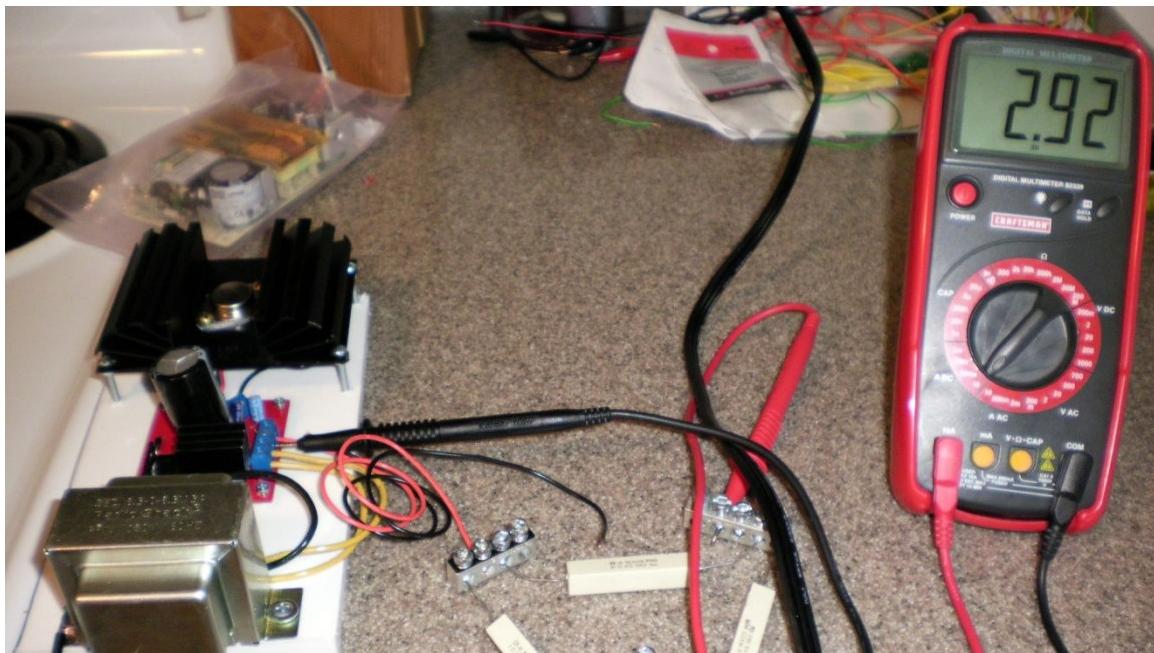


Figure 42: Power supply testing at full-load.

4.4 LED Driver

To test the LED drivers, we first connected the components required for the LED driver. We used the senior design lab and set everything up on a breadboard. Next, we connected the driver to the power supply and ground using all safety precautions necessary. We then determined how we should send a signal to the transistor to indicate that the circuit is to be turned on. We decided to bypass the transistor for testing purposes. For verification of the current the LED is drawing, we placed a voltmeter in series with the circuit. An example of this set-up is shown in Figure 43 below:

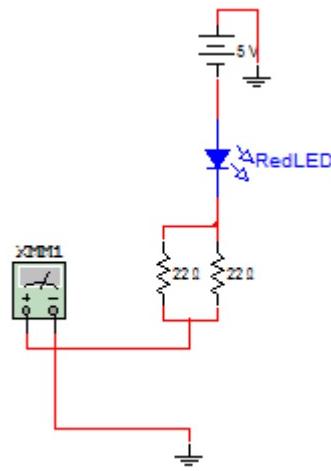


Figure 43: Current test for LED driver.

We verified that the current flowing through the circuit is below the maximum LED current of 500mA. We did this by connecting the voltmeter in series with the power supply and the transistor. We also verified that the proper voltage was being applied to the LED in order to turn it on. This voltage cannot exceed the forward voltage rating of each resistor. We did this by connecting the voltmeter in parallel with the node in which the LED is connected. We verified that these values were within operation range for each LED we used before we connected the LEDs to the circuit and before we connect the microcontroller to the circuit. Both of these components were much more expensive than the individual transistors and resistors so we wanted to be sure that they were protected against excessive voltage and current.

4.5 Pump Controls

Before PCB fabrication we bread boarded this circuit to ensure proper function. To test the pump control circuitry we first tested the relay. The relay is deactivated by the float switch when the water level falls below 6 inches. This was simulated by tripping the float switch and ensuring the relay opened when the float switch state was changed. Once we verified that the float switch and relay were working properly, we hooked up a test load to the circuit. This

removes any chance that the pump would be adversely affected by the testing process. We used a voltmeter to ensure that when the float switch was opened the relay power was not flowing through the secondary circuit which contains the pump. Before integrating the pump into the circuit we verified the primary and secondary circuits were functioning as designed. Once this was verified we incorporates the pump into the circuit and tested again. When testing was complete and the circuit was verified as functional it was incorporated into the PCB design.

When the PCB returned from fabrication and the preliminary testing of the PCB was complete we tested this circuit by changing the state of the float switch, which tripped the relay and removed power from the pump.

4.6 Nozzle and Cutter Mechanism

Testing of the cutter mechanism required the code to be completed since it develops the pulse width modulated output. Once the code was developed and tested we connected the outputs of the microcontroller to the two servo motors. Once the servos were connected, we manually initiated the mechanisms to ensure that the arms traveled into the correct position. After any adjustments were made we tested the nozzle and cutter together. We connected the nozzle to the pump and supplied the pump with sufficient water to prime the pump and to maintain proper operation. We energized the pump and aimed the nozzle at the catch basin. Then, we checked for proper stream clarity, length and height. After the proper stream was established, we pressed the manual cutter actuation button on the user interface panel and checked that the cutter arm moved into position and blocked the stream. We released the pushbutton and made sure that the arm moved out of the way and that the stream was once again properly established. Following a successful test of the first nozzle, we repeated the procedure for the second nozzle.

4.7 Motion Detector

Since the passive infrared sensor and the associated decoder chip cannot be simulated using Multisim or PSpice the circuit design was tested after the circuit was actually constructed. Once the motion detector was built, it was tested before it was connected to the microcontroller. Just a couple of additional components and a stopwatch were all that were necessary to test its functionality. Connecting a basic red LED, due to its lower turn on voltage, and a $500\ \Omega$ resistor, to limit current flow, in series with the output to ground gave us a visual indication of when motion was detected and allowed us to time how long the output remained high. The testing could have also been accomplished using a multichannel oscilloscope, with one channel of the oscilloscope connected to pin 14, input trigger from sensor, and one channel connected to pin 2, decoder output. During the following test procedure when the LED is on the pin 2 will be high.

We placed the sensor at a location that will simulate the final installation position. Once the circuit was assembled and the 5 VDC power supply was turned on we waited approximately 30 to 60 seconds for the sensor to stabilize. During the stabilization time the LED blinked several times. Once the sensor stabilized and the LED was continuously off we checked the circuit's operation. Waving a hand in front of the sensor triggered its operation and the LED illuminated. Once the LED was on, started the stopwatch and did not create any motion in front of the sensor. After approximately sixteen minutes the LED turned off as expected, and we recorded this time. This verified that the active high output time was working as calculated.

With the LED still off we moved in front of the sensor. Once the sensor was active and the LED turned on, we started the stopwatch again, and did not create any motion in front of the sensor for at least three minutes. After three minutes, we generated motion in front of the sensor again, then created no motion again in front of the sensor and ensured that the LED remained on for the same sixteen minutes following the second triggering. This verified that the retriggering function of the motion detector was working properly.

The final test was done to verify the range of the sensor. With someone watching the trigger signal on the oscilloscope, we started walking in from the left side and then the right side to see at what point the sensor triggered the motion detector. This verified the detection angle for the sensor. The last test was to start walking in from a distance at which the sensor was not triggered and then see how close to the sensor we needed to get to trigger the motion detector. After all parameters of the motion sensor were successfully tested, we then connected it to the microcontroller.

4.8 Ambient Light Sensor

To test the design of the ambient light sensor circuit, it was simulated in Multisim. The phototransistor cannot be modeled in Multisim so the phototransistor was replaced by a 2N2222 NPN transistor and a switch as depicted in Figure 444 below.

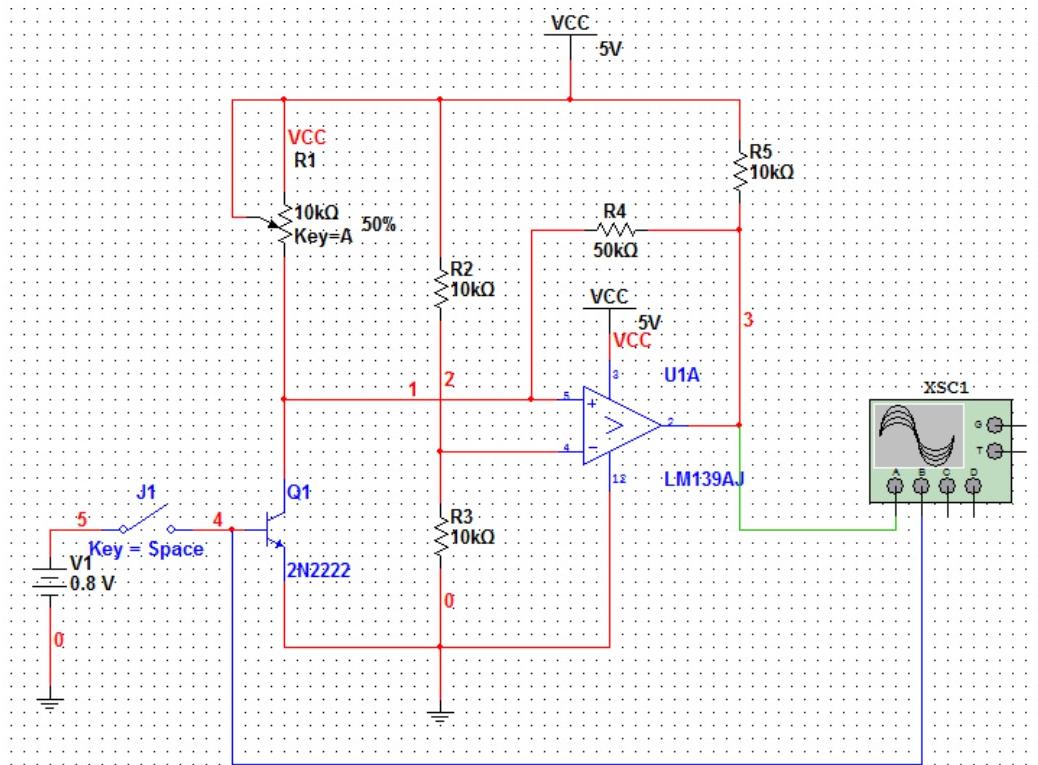


Figure 44: Ambient Light Detection Simulation Circuit

An open switch simulates a dark condition where the phototransistor will not conduct. The output on channel 1 (Green) is high. Once the switch closes, a daytime condition where the transistor conducts, the output drops to a low. The results of the simulation, in Figure 45, verify our design.

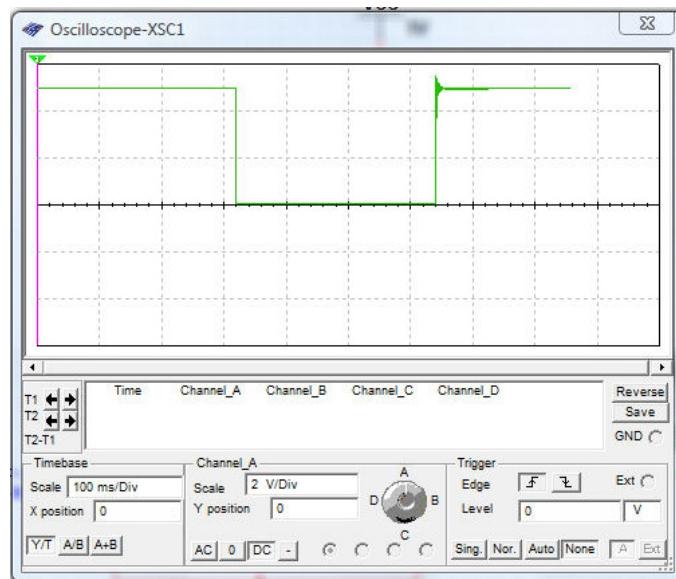


Figure 45: Ambient Light Detection Simulation Results

After the circuit was built, it was tested prior to connecting it to the microcontroller. A voltmeter was connected to the output pin of U1A and then the circuit was energized. An opaque cup was placed over the phototransistor and the output transitioned from a logic level 0 to a logic level 1 voltage. Once this was verified, the cup was removed and the voltage transitioned from the logic level 1 to a logic level 0. After the circuit operation was successfully verified it was then connected to the microprocessor.

4.9 Servo Driver

To test the design of the servo driver circuit, it was simulated in Multisim. To simulate the input from the microcontroller a switch and a 5VDC supply were substituted into the circuitry as depicted in Figure 44 below.

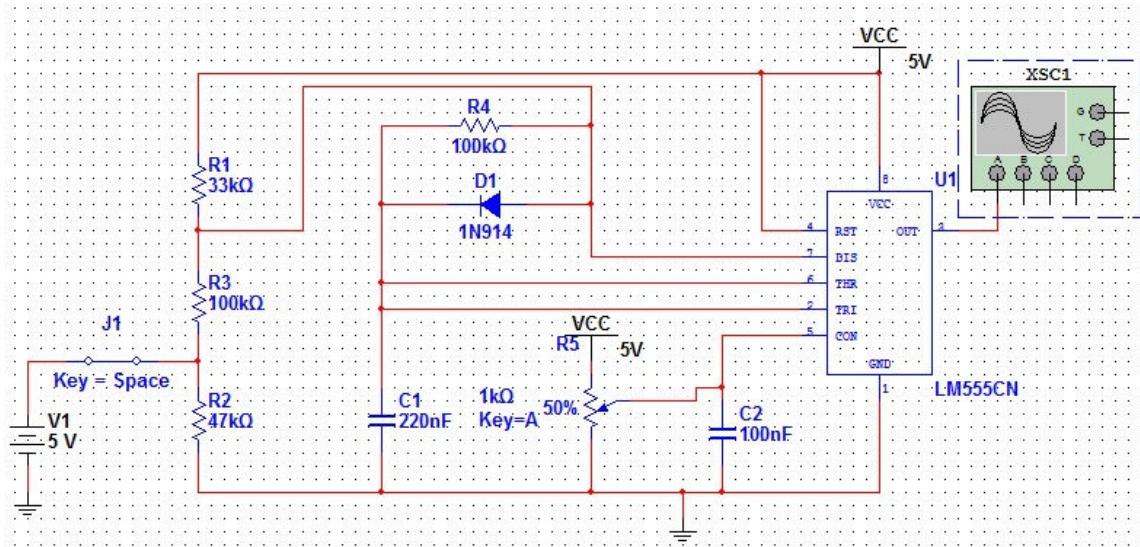


Figure 46: Servo Driver Simulation Circuit

A closed switch simulates a call from the microcontroller to cut/block the stream and an open switch simulates an uncut/unblock call from the microcontroller.

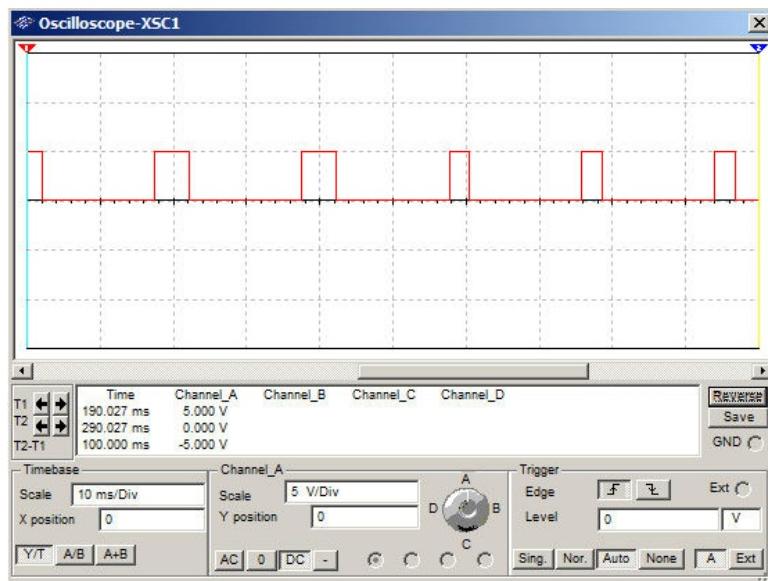


Figure 47: Servo Driver Simulation

After the circuit was built, it was tested prior to connecting it to the microcontroller. A graphical multimeter was connected to the output pin of the LM555 timer and then the circuit was energized. The pulse width was measured and then a 5 VDC signal was applied and the pulse width was measured again to verify that the two pulses were of the proper duration. The circuits were then connected to the servos and tested again to make sure that the servos maintained their position and travelled appropriately when a control signal was applied. Then the circuit was connected to the microcontroller for a final operational check.

Once the servos were fully tested and mounted on the mounting plate R5 was adjusted to place the cutting arm in the exact proper location in relation to the outlet of the nozzle.

4.10 Microcontroller Software Simulations

In order to test the software we developed we purchased the PIC16F887 development board. Then in accordance with the design software design plan described in the previous section we began writing the code. The test board allowed us to test each block of code as it was developed. This board allowed us to drive the LED circuits before the PCB board was spun. This intermediate step allowed for us to develop code in parallel with the PCB layout and spinning.

4.11 Microcontroller and External Circuit Interface

Before the microcontroller was placed onto the PCB board we ensured that all inputs to the PCB were correct. This was accomplished by doing voltage checks at the inputs to the microcontroller on the printed circuit board before the microcontroller was installed into the circuit. Once we were certain that the

inputs were all within the tolerances allowed for the microcontroller, we installed the microcontroller.

4.12 Final Testing Phase

A complete system test was conducted before final presentation of our project. In order to keep track of our testing procedures we developed a series of charts to complete to verify proper working conditions of our project.

5V Power Supply		
Location	Theoretical Value (V)	Actual (V)
Power In	120	123
Output from Step Down Transformer	12	15.4
Input to Voltage Regulator	10	13.2
Output from Step Voltage Regulator	5	5.02

Table 6: 5V Power Supply

LED Drivers		
	Theoretical Value	Actual
Input Voltage	5.0V	5.02V
Input Current	350mA	310mA

Table 7: LED Driver

Ambient Light Sensor		
	Theoretical Value	Actual
Input Voltage	5V	5.02V
Output for Lighted Situation	0	0.058V
Output for Darkened Situation	1	1.15V

Table 8: Ambient Light Sensor

Passive IR Sensor		
	Theoretical Value	Actual
Input Voltage	5V	5.02V
Output for no motion	0	0.055V
Output for motion	1	0.998V

Table 9: Passive IR Sensor

Pump Control Circuitry		
	Theoretical Value	Actual
Voltage on Primary Circuit	5V	5.02V
Voltage on Secondary Circuit when relay is closed	120V	122V
Current Through Secondary Circuit	3.4A	3.33A
Voltage on Secondary Circuit when relay is open	0V	0.100V

Table 10: Pump Control Circuitry

5 User Manual

To use the DLLF the user needs only to turn on the power switches located on the front of the electronics enclosure.

The user can then choose manual or remote control by toggling the DIP switches located on the PCB.

The first switch on the third bank of DIP switches indicated manual/remote mode. When positioned as shown the DLLF is in Remote mode. The user then selects the programs from the Remote shown in Figure 48.

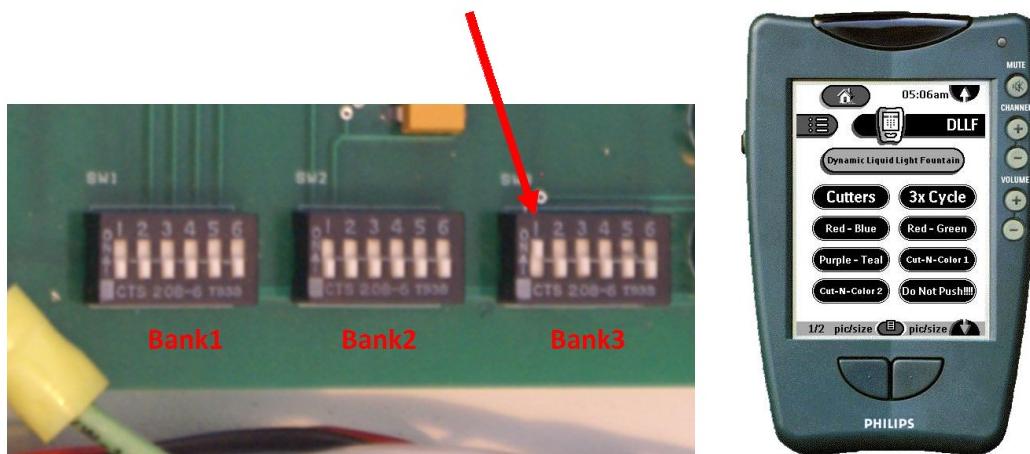


Figure 48: Remote Mode

For Manual Mode the user selects from the first two banks of DIP switches.

Bank1 allows the user to choose any combination of the RGB LEDs:

SW1-1 → RED

SW1-4 → RED

SW1-2 → GREEN

SW1-5 → GREEN

SW1-3 → BLUE

SW1-6 → BLUE

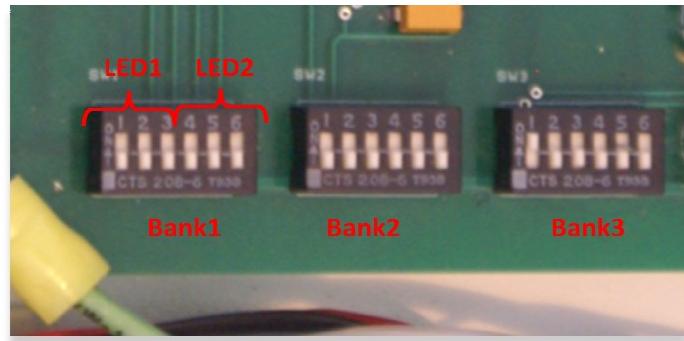


Figure 49: Manual Control

Bank2 allows the user to choose from the following programs:

SW2-1 → ROTATE

SW2-4 → JUMP BLUE

SW2-2 → JUMP RED

SW2-5 → NO LIGHT

SW2-3 → JUMP GREEN

SW2-6 → SERVO CONTROL

Finally, to turn off the DLLF the user should turn off whichever program is running. Then turn off the switches on the front panel of the DLLF.

6 Administration and Conclusion

6.1 Project Administration

The following block diagram is an overview of the general layout of our project. Each team member was assigned a series of responsibilities and those items were researched by the assigned individual. All design and layout decisions for the project were made by team consensus.

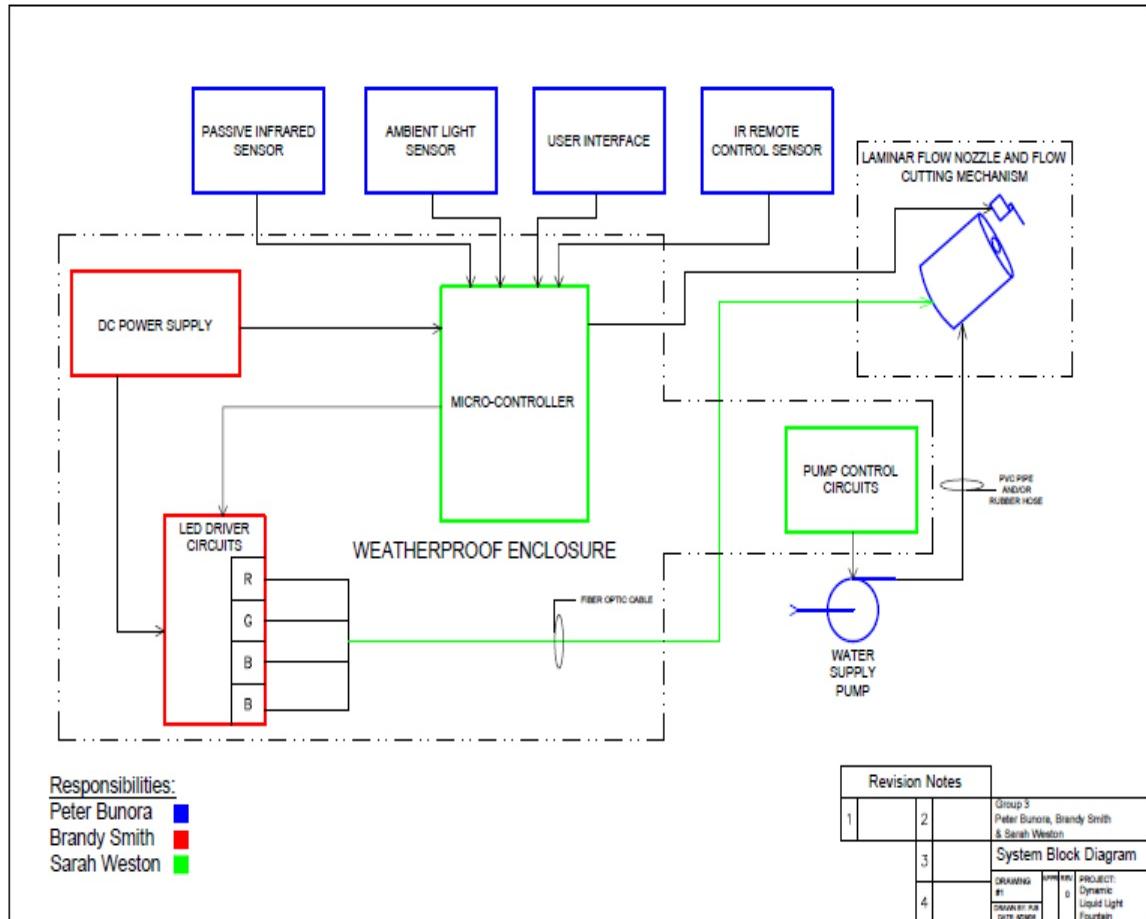


Figure 50: Project Block Diagram

In order to keep track of our progress, we developed the following chart which allows for a quick overview of the status of our project. As of December 14, 2009 the research and design was complete on all aspects of the Dynamic Liquid Light Fountain. We then began acquisition of components for bread boarding and software development.

Device	Group Member	Status
Passive infrared sensor	Peter Bunora	Research Complete
Ambient light sensor	Peter Bunora	Research Complete
User interface	Peter Bunora	Research Complete
IR remote control sensor	Peter Bunora	Research Complete
Laminar flow nozzle & flow cutting mechanism	Peter Bunora	Research Complete
Microcontroller	Sarah Weston	Research Complete
Pump control circuits	Sarah Weston	Research Complete
DC power supply	Brandy Smith	Research Complete
LED driver circuits	Brandy Smith	Research Complete
Microcontroller Development Board	Sarah Weston	Acquired
PCB	Sarah Weston	Research Complete
Signal Filtering for Audio Inputs	Brandy Smith	Research Complete

Figure 51: Tasking Responsibility

6.2 Budgetary/Financial Data

This project was group funded, with equal distribution of cost. A budget restraint of \$650.00 dollars had been put into place by the group member's financial situations. Originally we thought we had obtained sponsorship from RRI Energy, Inc. but that fell though. This price includes all incidental cost and equipment. In order to minimize cost we attempted to acquire many of the PCB components through manufacturer samples. It's common practice for manufacturers to send upwards of 10 free (including shipping) samples to companies to improve chances of companies implementing designs with new technology. By using a work address, our group attempted to acquire most, if not all, PCB level components using this method. This approach allowed us to decrease cost by approximately 10 to 20%. The following budget shown in Figure 51 and Figure 52 shows our complete expenditures including samples:

Component Description	Vendor	Quantity	Cost	Total
Electrical				
Resistors, capacitors, switches, etc.	Digi-Key	n/a	\$121.72	\$121.72
Resistors, capacitors, switches, etc.	Newark	n/a	\$59.48	\$59.48
Development Board	MicroChip	1	\$60.27	\$60.27
Fiber optic cable	Fiber Optic Products Inc.	1	\$37.00	\$37.00
LED connectors, glue	Radio Shack	1	\$5.10	\$5.10
RGB LEDs	E-bay	5	\$8.99	\$44.99
PCB Fabrication	4PCB	1	\$50.25	\$50.25
PIR	E-bay	1	\$2.00	\$2.00
Fresnel Lens	Electronics123	1	\$2.00	\$2.00
Float Switch	Chicago Sensor	1	\$15.20	\$15.20
Samples Received				
Headers	Millmax	2	\$0.00	\$0.00
Headers	Samtec	2	\$0.00	\$0.00
	Major League Electronics			
Subtotal:				\$398.01

Figure 51: Total DLLF Electronics Budget

Component Description	Value	Vendor	Quantity	Cost	Total
Mechanical					
Nozzle Parts		Lowes	1	\$30.39	\$30.39
Nozzle Parts		Home Depot	1	\$19.38	\$19.38
Drinking Straws (Nozzles)		Party City	1	\$9.90	\$9.90
Servos		E-bay	2	\$46.26	\$46.26
Pump		E-bay	1	\$37.00	\$37.00
TOTAL:					\$142.93
Grand Total:					\$540.94

Figure 52: Mechanical Budget

6.3 Project Timeline

In order to limit our stress and allow time for the group to work on other curriculum, we aimed to adhere to a strict schedule in the construction of our project. January 11, 2010 we began our initial prototyping of the Dynamic Liquid Light Fountain; this process lasted approximately 60 days. We completed our PCB design and layout and submitted the board for processing with 4PCB on March 10th and received our board back from them on March 16th. In parallel to this process we began software development for the microcontroller. Once the PCB was received, we performed our voltage and continuity checks on it as stated earlier and then soldered all components onto the board. We continued to troubleshoot the PCB including incorrectly entered connections on some of the

ICs due to lack of experience using PCB software. However, once this issue was resolved our circuit worked just as they did when they were bread boarded. Aside from this, our PCB and circuitry worked almost precisely as we had originally designed and planned.

Our initial demonstration with Dr. Richie was on Wednesday, March 17th. At this time, we had all circuitry bread boarded and had just received our PCB back from fabrication. We had also completed the power supply design and testing and had a steady 5V output. We were able to demonstrate some software completion as well including switching on one or more of the LED colors. We demonstrated how the passive motion detector circuit detected motion using an LED light and how the day/night sensor was able to switch from 0 to 5V when triggered by low lighting (covering the sensor with a cup). We also turned in our corrected Senior Design paper.

Shortly after this demonstration, we received our paperwork for the final presentation which was to be scheduled on April 21-23rd. We quickly obtained our panel of reviewers which consisted of Dr. Wasfy Mikhael, Dr. Elena Flitsyan, Dr. Thomas Wu, and Dr. Vik Kapoor and scheduled our final presentation for Thursday, April 22, 2010 at 2:00 pm in HEC 450 with a short demonstration outside the HEC building immediately following. On the day of the demonstration, we verified that everything we needed for our presentation was brought on campus. That morning, we practiced our power point presentation and then assembled our fountain. We did some last minute tweaking and verified that everything was in proper order before presenting our project to the committee. The timeline shown in Figure 53: Estimated Time Line is a summary of the milestones for our project.

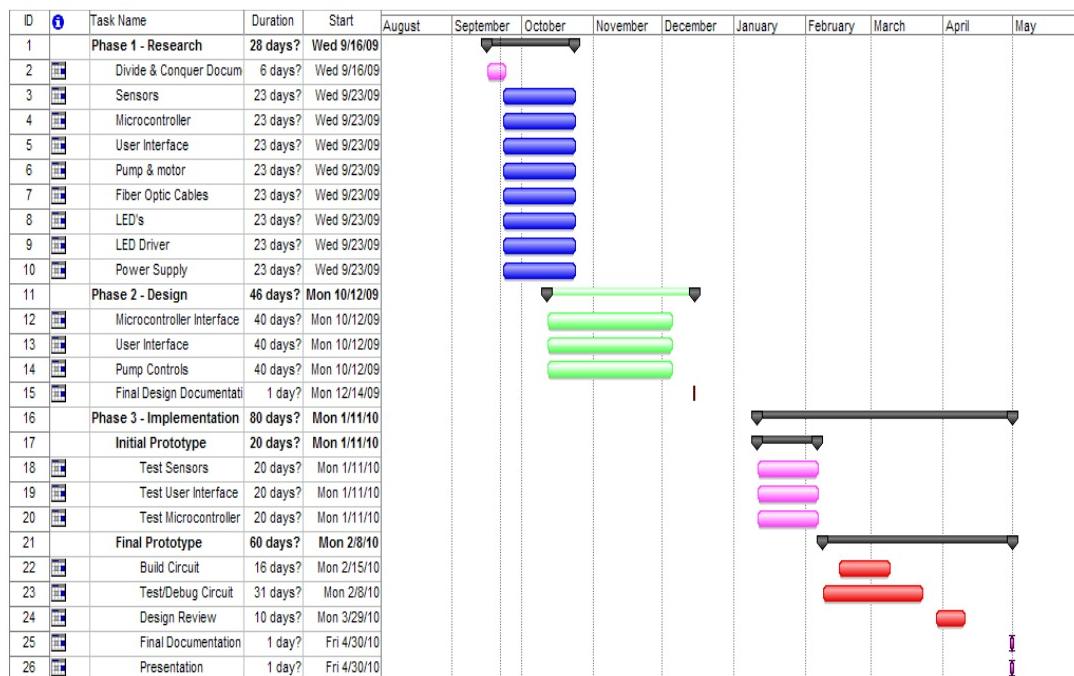


Figure 53: Estimated Time Line

7 Conclusion

The Dynamic Liquid Light Fountain has turned into a successful prototype. Should someone wish to purchase our project or build one of his/her own, it will provide them with a new and entertaining way to enhance the aesthetic value of their yard. At the beginning of the project, we had already received several inquiries as to when it was scheduled to be completed and demonstrated. There was also an interest from people on how they could purchase a fountain after it was complete. This level of interest increased our desire to ensure that we designed and built the fountain as correctly and visually pleasing as possible.

The team worked well together to overcome various design problems and found ways to provide an excellent design and final product with limited financial resources. When problems arose, no one pointed fingers at the other person; instead, we moved forward with the solutions to our problems in a timely manner.

A few of the problems that arose during the construction and implementation of our project are listed below with viable solutions for a future DLLF:

- Mechanical:
 - Problem: Smooth nozzle stream was difficult to obtain due to unsteady pump head.
 - Solution: Implemented surge volume which further smoothed the laminar flow.
 - Solution for future projects: Purchase a steadier pump that provides better volume control.
- Hardware:
 - Problem: While implementing the peripherals, 5V and ground line on header were at equal potential -> troubleshooting lead to the discovery of incorrect 4PCB symbols.
 - Solution: White wired the runs to correctly complete the schematic.
- Software:
 - Problem: Trouble implementing PWM control of the servos.
 - Solution: Created a daughter board containing additional hardware to allow microcontroller to send only digital outputs for servo control.
 - Problem: Color Organ relied heavily upon software implementation.
 - Solution for future projects: implement circuitry using hardware.

In summary, we thoroughly enjoyed designing and creating the Dynamic Liquid Light Fountain.

8 Table of Figures

Figure 1: General structure of a linear AC to DC power supply	10
Figure 2: Typical transformer (Image used with the permission of Wikipedia GNU Free Documentation.)	11
Figure 3: Non-center-tapped rectifying circuit	12
Figure 4: Center-tapped rectifying circuit	13
Figure 5: Power Supply circuit with filter capacitance shown.....	14
Figure 6: Typical application of a LP3872ES-5.0 voltage regulator (Image used with permission from National Semiconductor.).....	15
Figure 7: Typical application of a Micrel, Inc. MIC29300 series voltage regulator (Image used with permission from Micrel, Inc.).....	16
Figure 8: General structure of a switched-mode power supply	17
Figure 9: Comparison of a Linear versus Switched Mode Power Supply	18
Table 1: Typical characteristics of a high brightness LED.....	21
Figure 10: Typical constant current source with microcontroller	24
Table 4: Specifications for parts needed to build constant current source	25
Figure 11: An additional configuration to drive our LEDs.....	26
Figure 12: Example of a manufactured LED driver application (Image used with permission from LuxDrive).....	27
Table 2: Important characteristics of a dual operational amplifier	28
Figure 13: Typical configuration of the color organ.....	29
Table 3: Components required to build a color organ	30
Figure 14: A three-channel spectrum analyzer with LED displays	31
Figure 15: RC-5 Protocol Pulse Train (Image used with permission from San Bergmans)	32
Figure 16: Ultrasonic motion detector (Image used with permission from the Cypress Semiconductor Corp).....	33
Figure 17: Passive Infrared (Image used with permission from the Panasonic Co.).....	34
Figure 18: Fresnel vs. Plano Convex Lens (pending permission from Questex Media Group).....	35
Figure 19: PIR Sensor with Fresnel Lens (Image used with the permission of the Cypress Semiconductor Corp.).....	35
Figure 20: Bipolar Stepper Motor (Image used with the permission of Cyril Buttay)	39
Figure 21: HITEC HS-56HB Servo Dimensional Drawing (Image used with the permission of the HITEC RCD USA).....	40
Figure 22: LED to Fiber Coupler (pending permission from Fiber Optic Systems Inc).....	41
Figure 23: Living Lava Low Water Level Alarm (pending permission from Living Lava).....	45
Figure 24: Velocity Profile of Laminar Fluid Flow (Image used with the permission of Dr. Richard E. Klabunde).....	49

Figure 25: Simulated power supply circuit showing 120V AC input and a 5V DC output.....	53
Figure 26: LED driver circuit implemented with microcontroller.....	55
Figure 27: Infrared Remote Control Receiver Circuitry	56
Figure 28: PIR Example Application Circuit (Image used with the permission of the Micro Power Corp.).....	57
Figure 29: PIR Motion Sensing Circuit.....	58
Figure 30: Day/Night Circuit.....	60
Figure 31: Laminar Flow Nozzle	62
Figure 32: Outlet Plate for Laminar Nozzle	63
Figure 33: Inlet Plate for Laminar Nozzle	64
Figure 34: Servo Mounting Plate	66
Figure 35: Cutting Arm.....	66
Figure 36: Endplate Gasket	67
Figure 37: Relay Driver	70
Figure 38: PCB preliminary Layout	71
Table 5: Test conditions for power supply.....	77
Figure 39: Simulation of load conditions	77
Figure 40: Correct set-up of testing equipment.....	78
Figure 41: Values tested in order to verify the Power Supply is operating correctly	79
Figure 42: Power supply testing at full-load.....	80
Figure 43: Current test for LED driver	81
Figure 44: Ambient Light Detection Simulation Circuit.....	84
Figure 45: Ambient Light Detection Simulation Results	84
Figure 46: Servo Driver Simulation Circuit.....	85
Figure 47: Servo Driver Simulation	86
Table 6: 5V Power Supply	87
Table 7: LED Driver	87
Table 8: Ambient Light Sensor.....	87
Table 9: Passive IR Sensor	87
Table 10: Pump Control Circuitry	87
Figure 48: Remote Mode	88
Figure 49: Manual Control	90
Figure 50: Project Block Diagram	91
Figure 51: Tasking Responsibility	92
Figure 51: Total DLLF Electronics Budget	93
Figure 52: Mechanical Budget	93
Figure 53: Estimated Time Line	94

9 Appendix

9.1 Sources

Rozenblat, Lazar (2003).

SMPS Switching Power Supply Design.

<<http://www.smeps.us>>

Johnson, Dave (2009).

Circuit-Classic Linear 5v Power Supply Using 6.3vac Transformer.

<www.discovercircuits.com/DJ-Circuits/+5V%Transformer.htm>

“Schottky Diode.” Wikipedia

<http://en.wikipedia.org/wiki/Schottky_Diode>

Purdie, John C. (2003). *Switched Mode Power Supplies.*

<<http://www.electronics-tutorials.com/basics/switched-mode-power-supplies.htm>>

Arnold, Rob (2006) LED Center

LED Basics.

<<http://led.linear1.org/what-are-the-electrical-characteristics-of-leds/>>

Klipstein, Don (01/01/2000) The LED Light

L.E.D. Basics.

<<http://www.theledlight.com/led101.html>>

Kutscha, Tim (2005) *Making a Color Organ.*

<http://wolfstone.halloweenhost.com/ColorOrgans/clomak_MakingColorOrgan.html>

Beerten, Toon (2002-2009) *High Power LED Mood Lamp.*

<<http://www.electronics-lab.com/projects/games/005/index.htm>>

Cake, Aaron (09/20/2009) *3 Channel Spectrum Analyzer*

<http://www.aaroncake.net/circuits/3chspect.asp>

SB-Projects: IR remote control: Philips RC-5. Retrieved 5 Nov. 2009

<<http://www.sbprojects.com/knowledge/ir/rc5.htm>>

3 channel IR remote control. Retrieved 5 Nov. 2009

<<http://www.sixca.com/eng/articles/remote/>>

Stepper Motors. Retrieved 5 Nov. 2009

<http://www.omega.com/prodinfo/stepper_motors.html>

H-bridge - Wikipedia, the free encyclopedia. Retrieved 12 Nov. 2009
< http://en.wikipedia.org/wiki/H_bridge>

Hitec RCD : Servos. Retrieved 9 Dec. 2009
< <http://www.hitecrcd.com/servos/show?name=HS-56HB>>

CV Physiology: Laminar Flow. Retrieved 21 Nov. 2009
< <http://www.cvphysiology.com/Hemodynamics/H006.htm>>

IP Code - Wikipedia, the free encyclopedia. Retrieved 8 Dec. 2009
< http://en.wikipedia.org/wiki/IP_Code>

Circuit-ED - Electronic Development Products. Retrieved 17 Nov. 2009
< <http://www.circuit-ed.com/TouchPanel-Overlay-for-128x64-GLCD-P162C8.aspx>>

Choosing the Detector for your Unique Light Sensing Application Retrieved 30 Oct. 2009
< <http://www.engr.udayton.edu/faculty/jloomis/ece445/topics/egginc/tp4.html>>

Light/Dark Detector. Retrieved 30 Oct. 2009
< <http://www.aaroncake.net/circuits/lightdrk.asp>>

Dark Activated Switch. Retrieved 30 Oct. 2009
< <http://www.circuit-diagrams.com/dg21-Dark-Activated-Switch.php>>

About motion sensors. Retrieved 29 Oct. 2009
< <http://www.shed.com/tutor/sensors.html>>

Fresnel lens - Wikipedia, the free encyclopedia. Retrieved 31 Oct. 2009
< http://en.wikipedia.org/wiki/Fresnel_lens>

Ultrasonic Motion Sensor - Cypress Semiconductor. Retrieved 29 Oct. 2009
< <http://www.cypress.com/?rID=82>>

How to use Pyroelectric ("Passive") Infrared Sensors (PIR). Retrieved 1 Nov. 2009
< <http://www.ladyada.net/learn/sensors/pir.html>>

Stepper Motor Control. Retrieved 9 Nov. 2009
< http://www.pyroelectro.com/tutorials/stepper_motor/index.html>

PICServo Controller. Retrieved 9 Nov. 2009
< <http://www.digitalnemesis.com/info/projects/picservo/>>

Water lifting devices. Retrieved 7 Dec. 2009
< <http://www.fao.org/docrep/010/ah810e/AH810E05.htm#5.3.1>>

Centrifugal Pump | Centrifugal Pump Repair | Centrifugal Pump Training.
Retrieved 10 Dec. 2009
< <http://www.centrifugalmumpguide.com/>>

Inrush current - Wikipedia, the free encyclopedia. Retrieved 10 Dec. 2009
< http://en.wikipedia.org/wiki/Inrush_current>

Ultrasonic Motion Detector.pdf. Retrieved 28 Oct. 2009
< <http://web-ee.com/images/UltrasonicMotionDetector.pdf>>

The guide to laminar flow. Retrieved 10 Oct. 2009
< <http://laminar.forumotion.com/laminar-nozzle-talk-and-pictures-f1/the-guide-to-laminar-flow-t18.htm>>

How to identify your Sch 40 Pvc Pipe Size. Retrieved 10 Oct. 2009
< <http://flexpvc.com/PVCPIPESize.shtml>>

Miga Motor Company : Modern Motion : Shape Memory Alloy Actuators : Home.
Retrieved 4 Nov. 2009
< <http://www.migamotors.com/>>

Solenoid glossary - The Solenoid Company. Retrieved 4 No. 2009
< <http://www.thesolenoidcompany.com/glossary.php>>

Solenoid Basics. Retrieved 4 Nov. 2009
< <http://www.ledex.com/basics/basics.html>>

Fiberoptic Systems, Inc., Retrieved 15 Oct, 2009
<<http://www.fiberopticsystems.com/cust5.htm>>

PCB123, Retrieved 20 Oct 2009
<<http://wwwpcb123.com>>

Express PCB, Retrieved 20 Oct 2009
<<http://www.expresspcb.com>>

PCB Design, Retrieved 20 Nov 2009
<<http://wwwpcbdesign.org>>

USNA EL461, Retrieved 20 Nov 2009
<<http://www.usna.edu/EE/ee461>>

10 Permissions

10.1.1 Hitec HS-56HB

Hello Peter,

Thank you for choosing Hitec products. You may definitely use the spec sheet in its entirety for your senior design project.

Thank you,

Billy Tompkins
Customer Service Rep.
Hitec RCD, LLC
Multiplex USA

Phone (858) 748- 8440
Fax (858) 859-2618
12115 Paine St.
Poway CA, 92064

10.1.2 Panasonic

Hello Peter,

We have no problem with you using an image from our NaPiOn datasheet. Please let us know which ones you intend to use, and we can also help if you require something additional.

In return we ask that you provide a copy of your senior design paper to review the NaPiOn inclusion.

Attached is the most current datasheet - let us know if you have any questions.

Regards,
Tom Monczka
Product Manager
Technical Marketing Division
Panasonic Electric Works Corp. of America
Tel: (908) 464-3550 x2151
Fax: (908) 464-5719

<http://pewa.panasonic.com>

10.1.3 Cypress

Hello Peter,

Thank you for your interest in Cypress products.

In regards to your query below, please confirm you will not edit the material or any other content of the application note without explicit, written permission from Cypress. Please also remember to cite Cypress as the owner of the image.

As long as the above clauses are met, you can go ahead with using image of figure 7 from application note AN2105. Please let me know if you have any questions or need further information.

Regards,
Ashwin Varma
Cypress Customer Care

10.1.4 RC-5 Protocol

Hello Peter,
You have my permission.
Regards,

San Bergmans
www.sbprojects.com

10.1.5 Parabolic Velocity Profile

Peter,
You have my permission to use the figure you requested in your senior design paper. I wish you the best as you continue your studies.

Sincerely,
Richard Klabunde, PhD
Athens, Ohio

10.1.6 National Semiconductor

Dear Brandy,
National Semiconductor Corporation has received your request for permission to republish National Semiconductor's copyrighted material.
We need you to comply with the following requirements and you may do so:
We need a note from you that contains the following information from Section 1:

Section 1:
1. requester name, company, address, fax and phone number

2. professor name, contact person, university, address, fax and phone number for the paper, CD or the related book.
3. list of specific parts or files to be republished (or portions of datasheet or application notes, i.e. figure 12, section 1)
4. what quantity you will be printing
5. what amount you will be charging the end user for this information (i.e. the cost of the final publication)
6. what countries you will be printing in

You can send this information to:

National Semiconductor Corporation
Attention - Diane Trevino
3689 Kifer Road
Mail Stop G1-325
Santa Clara, CA 95051

Section 2:

1. In your printed paper or CD duplicated publication, you must acknowledge that you are using National Semiconductor's copyrighted material as described in <http://www.national.com/legal/> and insert the following:

Copyright © 2009 National Semiconductor Corporation
2900 Semiconductor Drive
Santa Clara, CA 95051, U.S.A.
All rights reserved
2. You must state that this information/material is reproduced with permission from National Semiconductor and reference our website at <http://www.national.com>.
3. You may use this information for only the purpose you have stated in your original request, i.e. to be included in a paper, printed book or CD. This material is not to be published on the internet.
4. By giving this permission, National Semiconductor does not allow you to use our product name, company name, etc. in any promotion, affiliation, or as sponsor of your products and services.

If you agree to the above, please sign and fax back this form to National Semiconductor at (408) 721-1304, ATTN: Corey Coronado.

Regards,
Web Business at National
You can forward the above information to people who come your way for permission to reprint for datasheets and application notes.

10.1.7 Micrel, Inc.

Hello Brandy Smith:

You have permission to use Figure 3 on page 17 of the MIC29xxx Datasheet in your paper. Please credit the figure to Micrel Semiconductor. You may have a problem as this datasheet on the Micrel Website is "Locked" and graphics cannot be clipped from the PDF.

You may be able to scan and then copy the artwork.

Thank you for your interest in Micrel products.

Regards,

Michael J. English
Staff Applications Engineer
Micrel Semiconductor
408 474-1291 Voice
408 474-1000 Fax
menglish@micrel.com Email

10.1.8 Luxdrive

Hello Brandy,

Absolutely. On a side note, we are very education centric and have a number of EE PHDs and professors from Vermont Technical College on our staff. If you need any further support, I am sure I can get you additional resources.

Best Regards,

Jon

Jonathan Wish
LEDDynamics, Inc.